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HONOURS THESIS

How Does The RBA Respond to Financial Stress?

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Declaration

I hereby declare that the content of this thesis is my own work and that, to the best of my knowledge, it contains no material that has been published or written by another person(s) except where due acknowledgement has been made.

Additionally, this thesis has not been submitted for award of any other degree or diploma at the University of New South Wales or any other educational institution. I declare that the intellectual content of this thesis is the product of my own work except to the extent that assistance from others is acknowledged.

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Roger Dong

3rd November 2014

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Abstract

Ensuring the stability of the financial system has been a longstanding responsibility of the RBA which has recently been forced to the foreground due to the global financial crisis. This thesis aims to investigate the impact of increases in the *aggregate* level of financial stress on monetary policy decisions. To conduct the analysis monthly proxies of inflationary and output gap expectations and an extended sample of the International Monetary Fund's Financial Stress Index, covering the period of 1997-2014 is used. Adopting a non-linear threshold vector auto-regression model I find that the central bank responds to increments in financial stress by reducing policy rates. Moreover, this magnitude substantially increases when instability further exacerbates under regimes of high financial stress. However, the size of these interest rate reductions may have been directly amplified by the outlying GFC period in the sample, which is a unique case in recent times. This especially holds true for estimations of monetary policy behaviour during the high financial stress regime.

1 Introduction

The recent financial crisis has served as a strong reminder to both central bankers and economists on the importance of maintaining financial stability in the economy. In a period of 6 tumultuous months between late 2008 and early 2009, the Reserve Bank of Australia (RBA) cut their policy rate by 375 basis points in a response to combat prevailing financial stress and deteriorating global conditions.

Within the context of monetary policy, the Taylor rule (Taylor, 1993) has been widely used as it stipulates a simple yet representative explanation of how central banks typically behave; adjust the nominal interest rate to changes in inflationary and output gap expectations. However, a simple Taylor rule would have over-estimated policy rates by around 200 basis points for Australia during this highly volatile period¹, raising questions as to whether additional economic conditions need to be reconsidered in monetary policy rules besides the level of inflation and the output gap.

The inclusion of financial stress indicators have often been proposed as an avenue towards improving the standard Taylor rule, with discussion intensifying recently. This was propagated by Taylor's testimony before the US House of Representatives in 2008, where he recommended a revision of the standard policy rule to incorporate credit spreads and to deduct a smoothed amount of the size of the credit spread from the interest rate target. Subsequently, this led to research highlighting the growing importance of addressing issues in the financial sector (Curdia and Woodford, 2010) as well as reigniting concerns of developments in asset prices for central banks. Additionally, through this unsettling course of events, the age old debate on if monetary policymakers should respond to changes in stress in a proactive (to 'lean' against the wind) or reactive (to 'clean up' afterwards) way has also been reinvigorated.

This thesis aims to examine how the Reserve Bank of Australia responded to changes in financial stress through their policy rate during the sample period of 1997-2014, using the recently constructed International Monetary Fund (IMF) Financial Stress Index which provides a *aggregated* view of financial instability in the economy rather than *individual* measures such as credit spreads or asset prices used in the past studies.

¹ According to estimations from Kendall and Ng (2013)

A Threshold Vector Auto-regression (TVAR) model is used as central banks are likely to react to financial stress in a non-linear way (Goodhart et al, 2009; Hubrich and Tetlow, 2012), where considerations for financial stability in interest rate setting may be limited during states of low or normal stress however will become important when financial distress becomes large (Baxa et al, 2013).

My key contribution is to analyze this problem empirically by assuming that central banks adjust their policy rate through a forward looking (Nelson 2001; Orphanides, 2003) rather than backward looking framework. To my knowledge, the current econometric literature on how central banks react to *aggregated* financial stress indices such as the IMF Financial Stress Index have used lagged rather than leading measures of inflation and the output gap for the context of Australia. By proposing an alternative specification and data sources, my model aims to minimize the downward bias of the effect of financial stress on monetary policy that has occurred in previous econometric literature. This is because if current or previous levels of inflation and the output gap are used (rather than *expectations*), the importance of the financial stress measure could potentially be overestimated as it may provide useful forecasting information on the output gap and inflation rate in the economy rather than being a genuine concern to central banks if they actually operate in a forward looking manner. Additionally, an extended sample period for financial stress past 2009M5 for Australia is employed. This is influential as financial stress remained high even after the financial crisis especially during 2010-12, which was not captured in previous studies potentially minimising estimation biases due to outlying RBA responses such as the series of dramatic interest rate cuts between October 2008 and February 2009.

Based on my estimations, I find a similar negative response of policy rates to elevations in financial stress like Baxa et al (2013). The magnitude of interest rate reductions is also significantly larger during periods of high financial instability which indicates a substantial non-linear relationship. This suggests that a *reactive* (Bernanke and Gertler, 1999) or ‘clean up’ strategy has been imposed over the past two decades. Additionally, there is also little evidence to suggest that a ‘leaning’ stance against financial stress has been adopted by the RBA during the low financial stress regime.

However, the robustness checks demonstrate that the model may be sensitive to the sampling period employed. I find that the strength of non-linearity towards

developments in financial stress between regimes diminish after the financial crisis period from 2008 onwards has been removed. This suggests that the elastic behaviour of policymakers during the recent financial crisis may be complicated and a unique case, therefore a threshold model with more than two regimes may be considered for future research.

The thesis will be broadly organized as follows:

Chapter 2 provides an overview of the theoretical and empirical literature for monetary policy rules with particular reference to financial stress. The motivations and background of the research will be summarized in this section.

Chapter 3 briefly discusses the key data sources used in the thesis, in particular the financial stress measure as well as the construction and transformation of the other variables used.

Chapter 4 describes the empirical framework used to analyse the thesis problem. The Threshold VAR estimation technique as well as the algorithmic procedure used to generate generalized impulse response functions and their confidence bands is discussed here.

Chapter 5 presents the key results of the research. I investigate and analyse the RBA policy reaction under various shock settings of my TVAR using a reduced form and structural VAR approach.

Chapter 6 outlines the robustness checks used against the main results. Alternative measures of the interest rate, model specifications and sample periods will be considered in this section.

Chapter 7 provides the key conclusions and implications of our study as well as limitations.

2 Literature Review

In terms of magnitude, the 2007-09 financial crisis has been of an order unparalleled in recent times. Nominal interest rates reached the zero lower bound in several advanced economies and the Reserve Bank of Australia (RBA) engaged in aggressive expansionary monetary policy by reducing the overnight cash rate from 7.00% to 3.25% within a 6 month period during the height of the crisis in order to stabilize the growing economic turbulence. As such this has rekindled the academic debate of the late 1990s on which monetary policy response is more appropriate for financial market developments; a proactive (Cecchetti et al, 2000) or a reactive (Bernanke and Gertler, 1999) one.

The literature review will be structured into six broad subsections. Initially, I provide a brief definition of financial stress as well as motivation for why central banks should or should not respond to stress and in what way. This is supported by coverage of empirical literature on how policymakers actually responded to financial stress in section 2.4. Arguments on why a forward-looking framework may be appropriate for modelling how central banks conduct monetary policy is analysed in section 2.5. Lastly, I discuss other important aspects such as macro-prudential regulation which has been proposed as an alternative solution to policy rate manipulation for curtailing financial stress, as well as adjustments in credit aggregates on potentially affecting my estimation in section 2.6.

2.1 What is Financial Stress?

At the most basic level, financial stress can be described as a level of interruption to the normal functioning of financial institutions, markets or infrastructures where the facilitation of a smooth flow of funds between savers and investors is impaired (Hakkio and Keeton, 2009). Unfortunately however there is not a prescriptive description of what is inclusive within this definition as Luci Ellis, the Head of the Financial Stability Department of the RBA suggests: *“there has not been much consensus in how to define that policy goal (financial stability). For some, it is about preserving market functioning; for others, it is about avoiding undesirable movements in asset prices or exchange rates”* (Ellis, 2014).

A more academic translation for financial stress references to increased uncertainty in the fundamental value of assets, information asymmetry and decreased willingness to hold both risky and less liquid assets in financial markets (Hakkio and Keeton, 2009) as being key criterion for marking the level of financial stress in the economy. To estimate some of these features measures such as changes in asset prices and volatility, credit spreads as well as financial imbalances are commonly used. For Australia at least, the RBA is primarily concerned with *'disruptions in the financial system so severe that it materially harms the real economy'* (Ellis, 2014), suggesting that the RBA responds to financial stress in a non-linear way, ie. more strongly when financial market disruptions are dire. How the RBA responds to less dramatic developments in financial stress or those that can be classified as potentially *'harmful to the real economy'* however is not explicit, therefore the next subsection will focus on discussing the evolution of the theoretical literature for monetary policy rules with particular emphasis to financial developments.

2.2 Should Central Banks Consider Financial Stress?

Prior to John Taylor's seminal 1993 paper on the 'Taylor rule', methods incorporating the new concept of 'rational expectations' had become prominent in many fields in economics including macroeconomics. What 'rational expectations' hypothesises is that agents' expectations will on average equal the true statistical expected values. As such, this favours central banks to adopt a monetary policy rule approach which is analogous to an optimal precommitted solution to a dynamic optimization problem (Kydland and Prescott, 1979; Blanchard and Fisher, 1989) rather than discretionary monetary policy, which is an 'inconsistent' or 'short sighted' solution. Despite appearing restrictive, Taylor (1993) argued that this does not necessarily imply monetary policy ineffectiveness but rather that credibility which has significant benefits such as shaping public expectations about inflation and thus anchoring those expectations towards price stability, can be gained through a well-defined policy rule. Additionally, a policy rule that responds to changes in the price level and output gap through the central bank funds rate helps ensure full employment and lower economic uncertainty. Although Taylor was able to show that a simple algebraic specification applying those features provided a reliable explanation on how G7 central banks conducted monetary policy (sample period between 1987Q1-1992Q3), there were two main caveats. Firstly, in Taylor's original 1993 model backward looking measures of inflation and the output

gap were applied. He contended that a forward looking framework would be more appropriate to better align with how central banks actually behaved. Secondly, that policy rules are occasionally subject to transitions in regimes ie. when it becomes clear that the current policy system in operation is not working well and a revised policy rule would be more appropriate. Taylor motivated this phenomenon with reference to exogenous oil price shocks in 1990 which caused temporary disruptions in the economy that required immediate action. This suggests that on occasion central banks will adjust their weights of importance on addressing inflationary and output gap pressures depending on conditions that arise in the economy, which may also help explain the dramatic reaction of central banks during the recent financial crisis.

With the success of monetary policy and the Taylor rule, most major central banks had inflation largely under control by the late 1990s. During this period however some attention shifted to the apparent increase in the level of financial stress particularly in the volatility of asset prices and discussions of the impacts of ‘significant contractions in real economic activity’ relating to historical asset price cycle busts became growingly prevalent. Two of the major academic debates during this stage were between Bernanke and Gertler (1999) and Cecchetti et al (2000).

Bernanke and Gertler (1999) which was the orthodox view, argued that central banks should view price and financial stability as highly complementary and mutually consistent objectives, where financial stress (in their paper measured by increases in asset prices and volatility) would already be indirectly accounted for under an inflation-targeting approach. As such, central banks should not respond to changes in asset prices unless they provide additional forecasting information on future inflation. Justifying this requires that the central banks can distinguish between when changes in asset prices are caused by fundamental or non-fundamental factors. This level of prophecy in most cases is highly unlikely as irrational behaviour by investors and ‘animal spirits’ are typically unpredictable ex-ante. Therefore the authors argue that an adhoc approach to developments in asset prices does not seem to be a viable option in most economic contexts as it is noisy and costly to evaluate their determinants in real time.

To the contrary however, Cecchetti et al (2000) brings up the highly valid point: *‘if asset prices (or financial wealth) are state variables in a macroeconomic system they should be responded to like any other state variable’*, suggesting that even when there

is error and uncertainty it would generally not be optimal to not respond at all to such movements in asset prices. Additionally, Borio and Lowe (2002) also dispute the argument that inflation targeting alone is a sufficient condition for addressing financial stability, since low inflationary environments can co-exist with phases of large financial imbalances.

Furthermore, Bernanke and Gertler (1999) suggested that one of the primary connections between asset prices and the real economy is through the ‘balance sheet channel’ and that financial frictions such as problems of information, incentives and enforcement typically leads to more and lower cost credit being offered to borrowers whom already have strong financial standings. How this translates to impacting the real economy is that when a decline in asset value occurs, this typically reduces available collateral thus implicitly increasing the level of leverage of borrowers and reducing their access to potential credit. With the health of balance sheets and credit flows being compromised, this has a negative effect on spending and aggregate demand in the short run as well as a longer run effect on aggregate supply by hindering capital formation and working capital. This can lead to significant feedback effects as declining sales and employment further exacerbates the cash flow problem potentially leading to further deteriorations in aggregate spending. This exacerbation is typically referred to as the ‘financial accelerator’ which has been widely used over the past two decades in analysing the effects of monetary policy within dynamic stochastic general equilibrium (DSGE) models in New Keynesian (NK) economics where unequal access to credit or debt collateralizations could have significant negative consequences on the monetary policy transmission mechanism.

These ideas are surprisingly not recent. With references as early as Fisher (1933) on the effects of adverse credit market conditions and Minsky (1982) discussing the role of balance sheets on financial stability. Recently, the non-linear negative effects experienced during the bust of a financial cycle have again been reinforced. Gambacorta and Marquez-Ibanez (2011) centres around the importance of the bank capital channel, where when bank capital is eroded they become more reluctant to lend and may deleverage causing a sharper economic downturn. This expresses the need for central banks to independently consider financial stability along with price stability in its policy objectives and the benefits of macro-prudential regulation on controlling asset price booms from spiralling into unstable territories. Additionally, Brunnermeier and

Pedersen (2008) outline how liquidity and market intermediation is severely impacted during a financial crisis due to non-linear increases in information asymmetry and risk aversion, which might explain why central banks may want to respond to credit spreads by reducing policy rates in order to improve confidence in the financial markets and restore efficiency in financial intermediation.

Although the impact and non-linear aspects of financial developments on the real economy suggests that strong expansionary action is required during episodes of high financial stress or an asset price bubble, whether a reactive (Bernanke and Gertler, 1999) or proactive approach (Cecchetti et al, 2000) was adopted during other states in the economy or ex-ante to a crisis is still somewhat ambiguous. So should central banks 'lean against the wind' of a potential asset price bubble or 'clean up afterwards'?

2.3 To Lean or To Clean?

Throughout history financial bubbles has been followed by sharp declines in economic activity (Kindleberger, 1978). Additionally, the departure of asset prices from fundamentals can lead to inappropriate investments that decrease the efficiency of the economy (Dupor, 2005). The basic idea is that keeping the policy rate higher than it would be otherwise contributes to holding back the rise in asset prices and also allows the fall in prices to be much milder than to allow a potential price bubble to perpetuate. In a way it acts as an insurance policy where growth will be lower during an expansionary phase at the benefit of reduced risk on negative developments further into the future.

However, this strategy of 'leaning against the wind' has been criticized by economists and policymakers such as Alan Greenspan due to three main arguments. Firstly, for the reasons stated in Bernanke and Gertler (1999), that bubbles are difficult to identify before it becomes too late. In addition, if the central bank fails to identify the imbalance sufficiently early, attempts to remedy the problem run the danger of adversely causing larger fluctuations in both asset prices and economic activity which is opposite to the initial intention. Secondly, is that adjusting policy rates are too blunt to address imbalances when the overall mood is optimistic. To do so would require a substantial increase in the policy rate which would have serious effects on the rest of the economy and because elements of irrational behaviour such as over-optimism and speculation are difficult to capture in models, policymaking using policy rates which are not a precision

instrument can be problematic (Nyberg, 2010). Lastly, because ‘leaning’ always runs the risk of accidentally popping an asset price bubble and because these phenomena behave non-linearly where the build-up might be gradual and continuous however the downturn to revert to fundamentals is typically much more sudden, dramatic and discrete, mistakes become very costly both economically and politically (Tetlow, 2004).

All these arguments favour the predominant strategy of cleaning up mistakes afterwards rather than to proactively address financial stress. However these views somewhat shifted after the initiation of the global financial crisis in 2007 where the costs and complexities of ‘cleaning up afterwards’ were much greater than originally anticipated.

With the financial sector becoming increasingly disrupted and negativity overflowing to the real economy, Taylor (2008) proposed an augmented version of the Taylor rule that included financial stress indicators in the form of credit spreads to better align with the monetary policy concerns and decisions occurring at the time. Taylor explained that increased credit spreads could affect the monetary policy transmission mechanism as well as the efficiency of financial intermediation, thus central banks should respond to credit spread developments by reducing policy rates proportional to credit spread increases.

Subsequently, revised policy rules with financial components was adopted in DSGE literature, including Curdia and Woodford (2010) which found that by adjusting for spreads the modified Taylor rule performed better than the standard Taylor rule in response to a range of shocks through the maximization of expected utility of households, however to a lesser degree than Taylor’s original proposal of a one to one response to credit spreads through the target policy rate.

In light of these improvements, the underlying processes still remain quite challenging and the appropriate monetary policy response sometimes is less clear. For example in Teranishi (2009) which derived a Taylor rule that responds to credit spreads, it was found that the dynamics were complicated and the policy response to credit spreads can be either positive or negative depending on the financial structure. In addition to credit spreads, augmentation to changes in other financial variables such as aggregate private credit were also studied (Christiano et al, 2008; Curdia and Woodford, 2010) however they find little evidence for augmenting the Taylor rule in response to credit volumes

since the size and sign of the desired response is sensitive to the sources of the shock and their persistence which are difficult to observe during operational policy making.

Further research by Gambacorta and Signoretti (2013) into extending models that consider frictions in financial intermediation (eg. Curdia and Woodford, 2010) by using augmented Taylor rules with asset prices that include a '*balance sheet channel*' and '*bank lending channel*', found that responding to asset prices even for central banks that do not consider financial stability as a distinctive policy objective, was desirable for output stabilization.

With reasonable consideration so far to policy rules that respond to credit spreads, asset prices and volatility which are major contributors to financial stress, other monetary policy considerations discussed in literature include exchange rates and the housing market, especially for a small open economy such as Australia.

For exchange rates the premise is relatively simple: should 'policymakers respond to a substantial appreciation in the real exchange rate by relaxing monetary policy'? (Obstfeld and Roghoff, 1995), or are responses to domestic factors such as inflation and the output gap sufficient as per the standard Taylor rule? Taylor (2001) found that directly reacting to the exchange rate did *not* yield greater improvements in monetary policy as fluctuations are already indirectly accounted for in the standard Taylor rule model. The argument was that in most open economy models currency appreciations such as the one discussed in (Obstfeld and Roghoff, 1995) would typically lead to two effects: a reduction in real GDP through expenditure switching as well as lower inflation through pricing benefits for imported goods. Since empirically these effects will typically occur with a lag, an appreciation of the real exchange rate will decrease the level of output and inflation in the future (ie. their expectations), which will increase the probability that the central bank will react by lowering their future interest rates. Leitemo and Soderstrom (2001) also find similar results where incorporating exchange rates to an optimized Taylor rule provided very minor improvements to economic outcomes however could sometimes lead to very poor consequences as the augmented Taylor rule with exchange rates is less robust to model uncertainty.

Another aspect that is frequently discussed for the Australian economy is the role of developments in the housing sector on monetary policy. A significant and recent example is the period between 2002-04 where the RBA made public warnings and

adjustments to their policy rate in an attempt to dampen house prices that were fairly clearly of a speculative nature due to a very sharp increase in housing prices stemming from the first home buyers grant in 2000 which was an initiative that offered a lump sum payment (up to \$15,000) to new home buyers or builders (RBA, 2003).

Although there is a significant time series correlation between housing price inflation and delinquency rates (Taylor, 2007), reacting to housing prices proactively fall under the same judgement issues as those discussed with asset prices earlier. Robinson and Robson (2012) estimated an open economy model using Australian data by extending the financial accelerator framework to include key components of housing construction to analyze the effect of housing shocks on the real economy. They found that the influence of housing sector shocks on non-housing related industries were not substantial. Although, the RBA may genuinely be concerned with abnormal developments in the housing sector, this will not be explicitly addressed within the thesis. The reason being is that these concerns are very cyclical and may also be non-linear in nature. Notable recent examples within our sampling period include 2002-04 which was previously discussed and 2007-09. Including just a housing measure (for example real housing prices) may potentially bias or complicate the estimates as although the housing market was of a concern for the RBA during 2007-09, more dramatic expansionary monetary policy was constrained by concurrent strong growth in the mining sector. This may be troublesome from a modelling perspective especially in consideration of the limited sample size, therefore I utilize a more parsimonious approach. This caveat will be addressed in further detail during section 3.2 where I discuss the choice of data.

2.4 Empirical Evidence for Policy Response to Financial Stress

Following from the debate between Bernanke and Gertler (2001) and Cecchetti et al (2000) on if central banks *should* respond to asset price volatility there have been a range of empirical studies done on if central banks actually *do* respond to asset price movements.

Initially, early contributions such as Thorbecke (1997) which imposed a zero interest rate response on impact and Bernanke and Gertler (2000) which used a Generalized Method of Moments estimation of the Taylor rule found evidence of only very small positive monetary policy responses to stock market fluctuations which were statistically

insignificant. However, an argument towards why these studies may have failed to uncover a significant relationship was because they failed to consider the simultaneous interdependence between interest rates and asset prices or only partially addressed this by using weak instruments, thus was not correctly accounting for an endogeneity problem.

In Rigobon and Sack (2003) the authors used an identification procedure based on the heteroskedasticity of stock market returns by examining how shifts in variance of stock market returns in comparison to monetary policy shocks affect the covariance matrix between interest rates and stock prices in a manner that is dependent on the responsiveness of the interest rate to equity prices, correcting for the endogeneity problem and finding a positive and significant response of monetary policy to stock prices. In their results they found that an unexpected rise in the S&P 500 Index by 5 percent increased the probability of a 25 basis point tightening by roughly 50 percent.

Chadha et al (2004) which used share of labour in national income as a more appropriate instrument for the output gap, also found positive monetary policy responses to asset price volatility in countries outside of the US such as Japan and the UK. However, in Siklos and Bohl (2009) the authors did not find a systematic reaction of the Bundesbank to German stock prices except during particular periods such as the 1987 stock market crash. Furthermore, Furlanetto (2011) which adopted the methodology from Rigobon and Sack (2003) analysed the response of the EU and six other inflation targeting countries to asset price movements, finding only Australia had a positive and significant response.

Empirical analysis outside of the central bank response to asset prices has also been explored recently. In Borio and Lowe (2004) the central bank response to financial imbalances are estimated for the US, Australia, Germany and Japan by using the ratio of private sector credit to GDP, inflation adjusted equity prices and their composite as the proxy. However, the results were generally insignificant although they found evidence that the US responded to financial imbalances in an asymmetric way by reducing the federal funds rate much more during periods of imbalance unwinding than tightening.

With reference to the US central bank reaction to credit spreads, Krisch and Weise (2010) estimated various regression models with both real time and ex-post data using a

credit spread index derived through principal components analysis. They found that the Fed has been systematically responding to changes in credit spreads negatively for the last quarter century however not by offsetting changes in credit spreads to the policy rate one-for-one as suggested in Taylor (2008) but a much weaker response. Through a time-varying framework the authors also found that Federal Reserve's response to credit spreads has somewhat weakened since the mid-1990s up until the financial crisis. Alluding to the possibility of potentially greater economic stability if the Fed response to credit spreads during that time was as responsive as the 1980s.

As a result of the academic movement for more consideration of the role of the financial sector as well as financial fragility in the economy, comprehensive indices that combine multiple sources of financial stress have been developed. Recently, Baxa et al (2013) utilized the International Monetary Fund (IMF) Financial Stress Index developed in Cardarelli et al (2011) to analyze the central bank response to financial stress using an augmented backward looking Taylor rule for a wide range of advanced economies including Australia, finding that most countries responded to increases in financial stress in a negative way by reducing their short-term interest rate. Utilizing this recent dataset has allowed for a more comprehensive analysis compared to previous literature that included only singular measures such as credit spreads or asset prices as a proxy for the overall level of financial stress in the economy relaxes the assumption that alternative stress measures need to perfectly co-move together. As the IMF Financial Stress Index considers a vaster array of factors by covering aspects of stress arising from the banking sector, securities markets and foreign exchange markets it has a very strong performance at predicting historical crises as well as recession dates (90%). In addition, since it is an aggregated index that covers the broad view of the level of financial stress in the economy, it is more likely to be closely aligned to the perceived level of financial stress of policymakers at each time period which will assist in allowing for a better empirical estimation.

However, to my knowledge the empirical literature has not explored how central banks respond to financial stress using an amalgamated measure that incorporates the role of the banking sector, credit spreads, movements in asset prices and volatility, as well as appreciations in the exchange rate as this dataset is relatively recent, through a forward looking framework for Australia. With the rational-expectations revolution over the past couple of decades it is not unreasonable to assume that monetary policy in

advanced economies are now conducted in a way that is optimized and forward looking. As such I attempt to address this by considering an econometric model that utilizes leading indicators in order to explore the problem through a more forward looking empirical framework.

2.5 Forward Looking Policy Rules

‘What the Federal Reserve will have to judge is not so much the question of where prices are or have been, but rather what is the state of the economy later in the year’ – Alan Greenspan, Federal Reserve Chairman, 1997

The recognition that monetary policy is conducted with a forward looking dimension has been long documented (Taylor, 1993) and empirically estimated in policy reaction functions for G-7 countries (Clarida, Gali and Gertler, 1998; Orphanides, 2001). Although met with some early critique on the viability of being made operational likening economic forecasting to weather forecasting (Friedman, 1959), central bankers in advanced economies are primarily concerned with future levels of inflation and the output gap since monetary policy typically affects the economy with a lag. Therefore, it is optimal to minimize expected deviations from their target pre-emptively. This forward looking set up nests the original Taylor rule as a special case, where the backward looking policy rule is sufficient when a linear combination of lagged inflation and the output gap can effectively forecast their future levels.

Recent empirical papers on the monetary policy response to financial stress have generally yielded negative coefficients during more unstable periods (ie. relax monetary policy when financial stress is high) which may be intuitive but potentially misleading if a forward looking specification is not adopted. This is because although a large positive shock in financial stress could affect the real economy through the disruptions described earlier (such as their effect on financial intermediation, transmission and deleveraging), it may also convey useful forecasting information about the economy such as the level of output and inflation in future periods. As such this may inconveniently place bias on the actual significance of financial stress to central banks using a backward looking model if they truly operate from a forward looking perspective.

Although there have been econometric studies using forward looking Taylor rule specifications with financial measures such as asset prices or credit spreads, these measures have not been combined broadly to generalize an aggregated level of financial stress in the economy which is of a higher concern to policymakers. Recent development into more comprehensive stress measures such as the IMF Financial Stress Index (Cardarelli et al, 2011) has made such research more applicable.

This thesis aims to empirically analyze if the RBA responds to financial stress by utilizing real time leading indicators to proxy expectations of inflation and the output gap for Australia through non-linear time series econometrics. As such it allows for a more neutral observation on how responsive central banks are to the negative feedback effects of high financial stress to the real economy.

In addition, I also implement an interest smoothing parameter term which is discussed in section 4.1 that allows the flexibility for central banks to only partially react to changes in expectations of inflation and the output gap which may be realistic for economic settings where there are high levels of uncertainty or prior beliefs.

2.6 Macro-prudential and Other Policy Alternatives

There are some limitations in the analysis however, in particular that I do not directly address developments in credit aggregates or other forms of intervention towards financial stability such as institutional policy changes which may be effective in addressing financial instability. Some recent notable examples include the Volcker rule/Dodd-Frank act in the United States which has direct implications on reducing financial market speculation as well as changes in capital adequacy requirements in Basel III such as countercyclical capital buffers that enforces bank capital to increase during periods of excess credit growth which aims to stabilize the risks of crises.

This may potentially bias the estimation in two key ways. Firstly, due to the method that financial stress indices are typically constructed (coincident and lagged indicators) it could lead to some minor distortions in the financial stress data near the end of our sample if unexpected policy announcements affect asset price volatility in a sharp way rather than through a six-month moving average calculation used to quantify some sub-components within financial stress indices. This leads financial stress to be slightly over measured during certain periods if public announcements on financial stability reforms

immediately reduce economic uncertainty and thus the behaviour of market participants to be less volatile. Secondly, but most importantly, if the RBA adjusts its policy rule (particularly to financial stress) due to changes in policy arising internationally or from the Australia Prudential Regulation Authority (APRA) that targets towards reducing financial stress (such as recent liquidity reform and Basel III implementation) our estimates on how reactive the RBA is to financial stress may be inaccurate as the policy response to financial stress may be both non-linear *and* time-varying if the RBA passes off some of its obligation to address financial stress to other economic authorities. However, because these changes are all very recent and some are still in the process of implementation, the severity of institutional policy changes towards our estimates are likely to be small. In mind of this, policy alternatives to adjusting policy rates will be discussed in more detail during the conclusions. As a robustness check I will use a particular subsample (1997M3-2007M6) of the data that excludes these policy changes as well as the financial crisis in section 6.3.

In consideration of credit aggregates, I will also re-evaluate the model by replacing the official policy rate to the interbank rate in the money market in section 6.2. Although both rates are quite similar, the latter is more sensitive during periods of crisis as it additionally considers liquidity conditions which are affected by unconventional policies such as changes in credit aggregates (Borio and Disyatat, 2009).

3 Data

I consider macroeconomic data for Australia between the period of 1997M3 and 2014M6 with a total of 208 observations. Data series used include the RBA overnight cash rate, Melbourne Institute's survey of consumer inflationary expectations, the National Australia Bank's capacity utilization measure and the IMF Financial Stress Index (FSI) all of which are of monthly frequency and are sourced from Datastream, the RBA and the International Monetary Fund².

This chapter is structured into four subsections. Firstly, a justification on why the IMF financial stress measure is appropriate for the study as well as a brief discussion on how it is constructed is presented. Secondly, I outline how I intend to proxy expected levels of inflation and the output gap as well as any limitations that may arise within the data used. Sections 3.3 and 3.4 will present statistical hypothesis test results on granger causality and unit roots within the data structure and their implications will be briefly discussed.

3.1 IMF Financial Stress Index

Since the global financial crisis of 2007, development into financial stress measures have been steadily expanding for many advanced economies. Recently, continuous stress indicators have begun to replace discrete crisis indicators (such as Kaminsky and Reinhart, 1999; Eichengreen and Bordo, 2002) due to some their advantages. In particular that it allows for a richer observation into the level of stress outside of crisis states which are historically scarce. This is an important aspect in regards to the thesis question as I aim to model for non-linear monetary policy responses to movements in financial stress. In addition, these new continuous measures are generally constructed using a more data driven rather than narrative approach used in some earlier discrete financial stress measures which may potentially avoid measurement bias through ex-post data construction.

² Further details in regards to the data used, are also summarized in Appendix A.0.

Generally, financial stress indices attempt to capture developments in the financial and banking sector with relation to changes in the level of information asymmetry, uncertainty and liquidity. Typically credit spreads, asset prices and volatility measures are used to achieve this however specific variable selection and aggregation procedure can differ depending on context.

Recently however, the IMF has proposed a comprehensive FSI that considers the banking sector as well as the securities and exchange rate markets which comprehensively cover the primary channels of financial instability. This has been made available for a large group of advanced economies including Australia in Cardarelli et al (2011) and follows a similar approach of construction to earlier indices developed by Illing and Liu (2006) for Canada and other private sector companies such as BCA research for the United States economy.

The IMF financial stress index is constructed by using high frequency data where price changes are compared to previous or trend values and are standardized and aggregated using variance equal weighting. Performance of the index was robust to different weighting schemes for different countries and aligns very strongly with actual episodes of banking related financial crises (90%)³. In addition, since the index is constructed in a standardized way, it allows for easy comparison across countries.

The IMF FSI considers three main channels of stress; arising from the banking sector (banking sector beta, TED spread and inverted term spreads), securities market (corporate debt spreads as well as the return and time-varying volatility of the stock market) and foreign exchange markets (volatility of the nominal effective exchange rate).

$$\text{IMF FSI} = (\text{Banking beta} + \text{TED spreads} + \text{Inverted terms spreads}) + (\text{Corporate debt spreads} + \text{Stock market returns} + \text{Stock market volatility}) + (\text{Exchange market volatility})$$

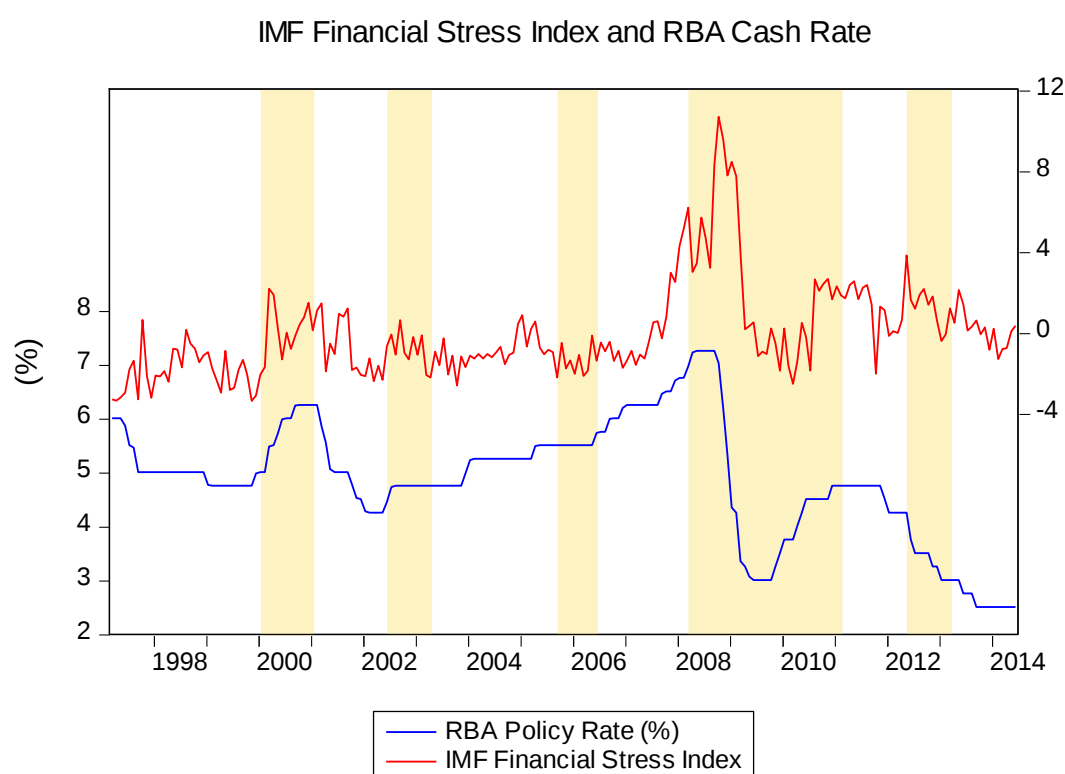
³ This is calculated by also considering the *duration* of crises classified in economic literature. If episodes are identified more broadly to allow a larger window of error of a few quarters, the FSI captures 100 percent of all historical banking crises from the sample period of 1980-2009 for seventeen advanced economies.

Each variable is demeaned (using the arithmetic mean) and divided by its standard deviation to become standardized. To yield the aggregated financial stress level for an individual economy the seven individual components are aggregated.

For interpretation, a value of zero for the FSI implies neutral financial stress conditions on average across the subindices; while positive values imply financial strain (i.e. prices, spreads etc. are on average above historical means or trends). A value of 1 indicates a positive one-standard deviation from average conditions across subindices and values above 1 have been indicative of historical crises. Although the FSI could in practice be custom tailored for an individual country such as Australia this may potentially complicate the signal extraction problem, therefore the standard and parsimonious IMF definition for financial stress is used without further transformations.

Detailed descriptions on how each individual subcomponent is calculated and the motivations for their inclusion in the IMF FSI are discussed in detail in Appendix B.

Figure 3.1: Relationship Between Financial Stress and Policy Rate



The above chart plots the IMF financial stress index (*red*) alongside movements in the RBA policy rate (*blue*) during our sampling period. Since Australia has not experienced an official economic recession over the past two decades, I use the Organization of

Economic Development's (OECD) Reference Turning Points and Component Series data to indicate periods of contraction in the Australian economy (*shaded in yellow*) to generally illustrate that moments of slower growth roughly reconcile with periods of higher financial instability.

For Australia, the three most significant periods of financial stress include the dot com bubble in 2000, the global financial crisis in 2008 and the prolonged period of market instability during 2010-12. Surprisingly, financial stress was not particularly abnormal during the Asian Financial Crisis for Australia in 1997, however financial stress for the period after the propagation of the global financial crisis lingered at a high level as the financial markets remained volatile due to concerns in Europe⁴. Periods of lower levels of financial stress are also represented for values below zero, which are typically before a crisis episode. For example, just before the 2000 dot com bubble and the 2002-06 period prior to the global financial crisis. The general relationship between the two series of the policy rate and financial stress suggest some level of co-movement typically with changes in the policy rate leading negative changes in financial stress, especially during the 2008-09 period where financial stress subsequently declined after the sharp fall in short term interest rates. This shows some preliminary evidence that the RBA does consider financial stress in its policymaking. However, inferences based on this simple diagram may be potentially misleading as it does not control for changes in inflation as well as the output gap, which are heavily considered by the RBA and could also influence each other in an endogenous way. As such, to gain a richer perspective, further comments will be refrained until the results of the model are analysed in Chapter 5.

3.2 Proxies for Expected Inflation and Output Gap

To proxy the RBA's inflationary expectations for the study the Melbourne Institute's Consumer Inflation Expectations Survey which is a seasonally adjusted monthly data set is used. The survey produces a direct measure of inflationary expectations as *consumers* are asked on how much they believe prices will change over the coming 12 months.

⁴ The Eurozone crisis led to prolonged market volatility in the Australian financial markets due to fears of sovereign default in many European states. This particularly intensified from 2010-12 amid concerns in Greece, Ireland and Portugal and a series of negative credit ratings reductions (Reuters, 2012)

Other potential candidates included the *business* inflation expectations survey dataset from the Melbourne Institute. Although this series may be more closely aligned to the actual expectations of inflation for the policymaker, the survey is conducted at a quarterly basis therefore utilizing this dataset would reduce the sample size from 208 to 52 observations. This is a significant cost as it will greatly affect our statistical power due to reduced degrees of freedom; especially so since a non-linear econometric estimation method will be used. Because of this, the *business* expected inflation measure will not be employed for the study. However, justifying that *consumer* expected inflation is a sufficient proxy for the inflationary expectations of the policymaker requires some faith into the assumption of rational expectations where agents know the true structure and probability distribution of the economy, ie. that the consumer's expectations of inflation aligns closely with those of the policymaker, which may not always hold in practice. The implications of this imperfection is that if the expected inflation measure used over (under)estimates the true inflationary expectations of the policymaker, the estimated response from the model will tend to under(over) estimate the significance of an inflationary shock to policymaking.

To estimate the expected output gap for each period I use a linear de-trending method for the NAB's monthly capacity utilization data series. The capacity utilization rate measures the level in which an industry is operating at or below full capacity, where full capacity is defined as the maximum desirable level of output given the firm's existing capital equipment and other fixed inputs in the short-run. The NAB constructs the capacity utilization rate by asking a diverse range of respondents from various industries on what the capacity utilization rate is currently at for their firm and taking the average⁵.

Although the Hodrick Prescott (HP) filter is widely used as a method for output gap estimation, some studies have shown that they perform poorly compared to other de-trending methods. Rzhetskyy (2008) applied six different de-trending methods (linear and quadratic time trend, band-pass filter, unobserved component model and Beveridge-Nelson decomposition) and found that the linear de-trending method with a 80 period rolling window performed the best at forecasting US Greenbook data which

⁵ Possible response selections are allocated into ten percent bands, with a sample size typically of around one hundred different respondents.

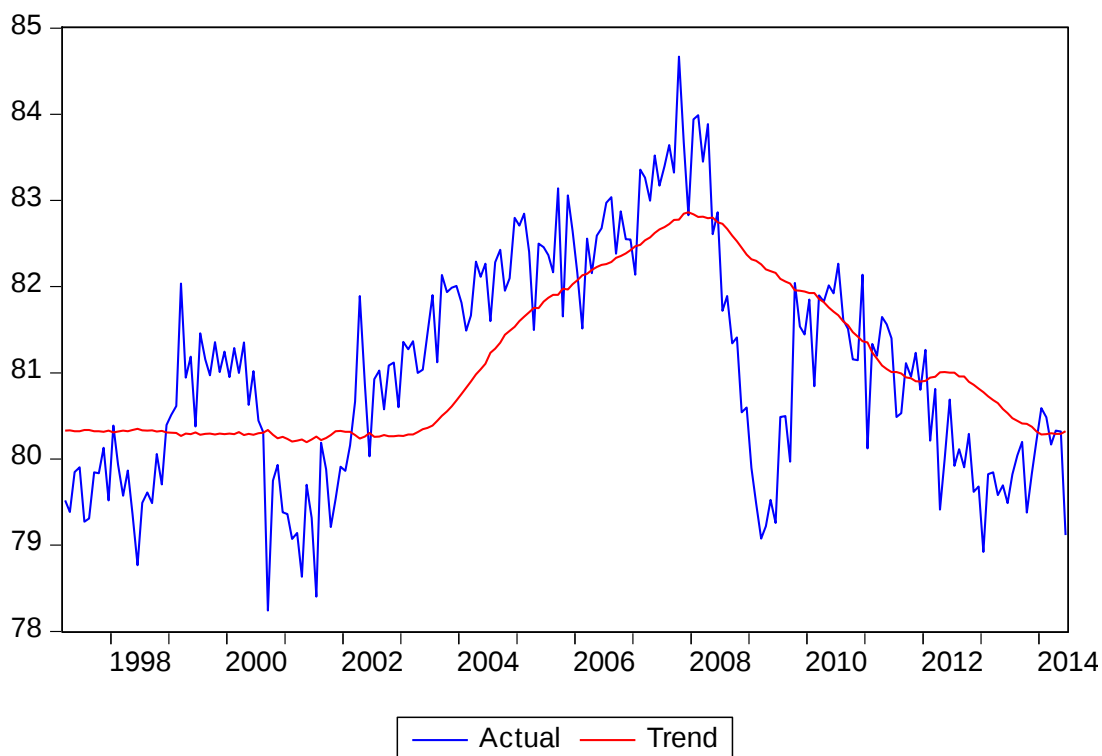
provides the Federal Reserve's real time forecasts of inflation and the output gap during the 1969:1-1977:4 sample period.

Unfortunately Greenbook estimates are not available for Australia, therefore justifying a real time expected output gap estimate for the RBA remains subjective. To proxy the RBA's expected output gap, linear de-trending is applied to the capacity utilization dataset and then divided by its trend value ($\frac{y-y^*}{y^*}$) to obtain a percentage form of the output gap. As abnormal increases (decreases) of capacity utilization from its long term stable rate signals increased (decreased) output in future periods, typically an expansionary or contractionary gap would follow. To decide the time horizon or rolling window length for our de-trending method it requires a balance between a long enough window length in which production factors are less affected by cyclical fluctuations and more so by structural factors (eg. changes in productivity); however short enough so that there is sufficient variability in potential production that avoids causing the amplitude of the divergences in output to be profoundly high (European Commission, 2003)⁶. Since the sample period of Australian capacity utilization data is quite short (1997M3-2014M6), I choose a moderate rolling window length of 40 monthly periods that is constructed in a dynamic way where initially the trend value is calculated using purely forward looking data that converges to a combination of 35 backward looking and 5 forward looking observations over time.

⁶ *'Statistical Methods for Potential Output Estimation and Cycle Extraction'* from the European Commission in 2003.

Figure 3.2: Linear De-trending of Capacity Utilization

Actual and Trend Capacity Utilization Rate (40 period window)



The benefit of this technique is that it allows for the preservation of sample size without the need for trimming, however comes at a cost of potential biases in calculation. This is because since the dynamic selection of observations in the rolling window is based towards selecting purely forward looking observations during the start of the sample (between 1997-1999) the output gap may potentially be upwardly biased during this period (since capacity utilization can be defined as $\frac{\text{actual output}}{\text{potential output}}$) if we anticipate that potential output in the economy grows over time (due to continual improvements in productivity and technology) since future values of capacity utilization in reference to capacity utilization today will be understated if potential output has increased. Since the capacity utilization series for Australia has been relatively stable over this period however, it is anticipated that the implications of bias through using this method will not be severe.

3.3 Unit Root Tests

Since time series models that assume stationarity will be used to obtain my results, I conduct the Augmented Dickey Fuller (ADF) and Elliot Rothenberg and Stock (DF-GLS) unit root tests on each data series to confirm if additional data transformation may be needed.

Use of the ADF test is standard within time series econometrics literature, where the null hypothesis is that the series contains a unit root or is $I(1)$ against the alternative that it is $I(0)$ or stationary by assuming that the dynamics of the data follows an ARMA structure⁷. The DF-GLS test is a modified version of the ADF test where the time series is transformed via a Generalized Least Squares (GLS) regression before performing the unit root test. Elliot, Rothenberg and Stock (1996) have shown that their modified test allows for significantly greater power than the standard ADF test and other prominent unit root tests such as Phillips-Perron. The lag length in both tests were determined by minimizing the Bayesian Information Criterion (BIC), which imposes a larger penalty term than the Akaike Information Criterion (AIC).

Both unit root tests were applied on the *levels* of the RBA policy rate, expected inflation and financial stress measure. Additionally, both tests were also utilized on the expected output gap measure, which has already undergone some data transformation; discussed previously in (3.2).

Based on the ADF test, the null hypothesis of a unit root could not be rejected in both the interest rate and inflation series. However, by using the more powerful DF-GLS test the null hypothesis of a unit root in the inflation series was rejected. Whether inflation is best treated as a stationary or non-stationary variable depends on the country of context as well as the test procedures used as discussed in Ng and Perron (2001), where they conducted a wide variety of unit root tests on quarterly data for G7 countries. However, Levin and Piger (2004) showed that once a structural break is accounted for the null hypothesis of a unit root was rejected at the 95% confidence level for 29 out of

⁷ The ADF test is estimated by estimating the following test regression:

$$y_t = \beta' D_t + \phi y_{t-1} + \sum_{j=1}^p \psi_j \Delta y_{t-j} + \varepsilon_t$$

Where D_t represents the deterministic terms and Δy_{t-j} captures the serial correlation. The ADF t-statistic is obtained as $ADF_t = \frac{\hat{\phi}-1}{SE(\phi)}$

the 48 inflation series, including for Australia. From an intuitive standpoint, if the RBA has been targeting inflation and is effective at doing so then inflation can be thought of as a stationary series. This is consistent with my sampling period as it begins in 1997 (after inflation targeting was introduced in 1993), therefore no further transformations were performed on the expected inflation rate series.

Since the null hypothesis of a unit root could not be rejected for the interest rate variable, the series was differenced to obtain stationarity. This may remove some potentially valuable long term information regarding the level of the interest rate when certain shocks occur which will be discussed later on in the thesis in section 4.7.

Finally, both the financial stress and expected output gap measures were shown to be stationary for the unit root tests, therefore they do not undergo further transformation. A detailed summary of these results are presented in Appendix A.1.

3.4 Granger Causality Tests

The Granger causality test is a statistical hypothesis test used to determine if lagged values of one variable is useful in the forecasting of another, summarizing linear correlational relationships. Since it exploits the direction of the flow of time to achieve a causal ordering of associated variables, it may provide some useful information towards the model building process of the VAR system discussed in section 4.2.

Table 3.4: Granger Causality Tests with P-Values

$\Delta INT \rightarrow FSI$	$FSI \rightarrow \Delta INT$	$\Delta INT \rightarrow GAP$	$GAP \rightarrow \Delta INT$	$\Delta INT \rightarrow INF$	$INF \rightarrow \Delta INT$
0.1931	0.0000	0.0168	0.0053	0.5456	0.0000

Columns 1 and 5 show that the null hypotheses of ‘changes in the policy rate *does not* granger cause financial stress; or inflation respectively’ could not be rejected. The first result is somewhat expected, as financial stress behaviour can be thought of as being partly exogenous, where changes in the policy rate may not necessarily be effective on affecting the path of FSI. In regards to the relationship between changes in the policy rate on granger causing expected inflation, the weak relationship may have been due to the inflation series being highly persistent. Re-conducting the granger causality test between the differenced policy rate and differenced inflation series show that they both granger cause each other ($p=0.000$). Additionally, granger causality tests were also conducted between the output gap and inflation, finding that the output gap granger causes inflation ($p=0.037$) however inflation does not granger cause the output gap ($p=0.479$). All tests were conducted and generally robust to various lag lengths (between 1-4), with a chosen lag length of 2 periods presenting the results above.

These results however should be viewed with caution for two main reasons. Firstly, because the granger causality test relies on the assumption that the true relationship can be represented in a pairwise way, this could sometimes lead to spurious results if there is an omission of relevant variables or if information is only partially observed. Additionally, based on the results of our sup-wald statistical tests discussed in section 4.3, there is strong evidence of a non-linear relationship between our variables whereas the Granger causality test (Granger, 1969) only stipulates a linear relationship.

4 Methodology

This chapter focuses on discussing the key empirical methods used to analyse how the RBA's responds to economic developments including financial stress. Section 4.1 provides a brief outline of the Taylor rule, which provides some of the theoretical motivations underlying central bank interest rate decisions. Section 4.2 discusses the threshold vector auto-regression (TVAR) model and empirical approaches used to estimate my results. A structural threshold VAR identification method is specified in Section 4.3, which supplements the reduced form TVAR analysis. Details on the estimation procedure for the threshold value as well as non-linearity tests will be discussed in section 4.4. Since impulse responses functions (IRFs) are important to our analysis of how the RBA responds to unexpected movements through the adjustment of their policy rate and because IRFs are computationally more challenging when dealing with non-linear models such as the TVAR, sections 4.5 and 4.6 will describe how generalized IRFs and their confidence bands are calculated. Finally, methodological limitations will be discussed in section 4.7.

4.1 Modified Monetary Policy Rule

The original backward looking Taylor rule in Taylor (1993) is represented as follows:

$$r_t^* = i^* + b_1\pi_t + b_2y_t \quad (4.1A)$$

Where r_t^* is the target policy interest rate, i^* is the 'neutral' interest rate or desired nominal rate when both inflation and output are at their target levels, π_t is the current inflation rate (over last four quarters) minus a target and y_t represents the current deviation of output from its potential level. Based on the estimations of Taylor's sampling period coefficients of 1.5 and 0.5 were defined respectively for b_1 and b_2 . Subsequently however, forward looking policy rules relating the short term interest rate to expectations in inflation and the output gap have been shown to be more successful than Taylor's original backward-looking specification (Orphanides, 2003). A forward looking monetary policy framework is justified as the impact of changes in monetary policy affects the economy with a lag thus the policy maker's primary concern is not where the level of inflation or the output gap is today, but in forthcoming periods.

Therefore the definitions of π and y_t are modified to represent the *expectation* of the excess inflation rate (calculated by expected inflation minus a fixed target level of 2.5%⁸) and output gap in the future for the policymaker. Since in practice these are unobtainable as they are not made public by the RBA, they will be proxied by the measures discussed previously in section 3.2. In addition the level of financial stress in the economy during each time period is represented as s_t .

Such an augmented Taylor rule that encapsulates forward looking policymaking as well as considers the level of financial stress in its decisions can be defined as:

$$r_t^* = i^* + b_1 E(\pi_{t+h}) + b_2 E(g_{t+h}) + b_3 s_t \quad (4.1B)$$

Where $E(\cdot)$ refers to the expectation formed conditional on information at time t when the policy rate is set at each monthly period. Therefore $E(\pi_{t+h})$ represents the expected inflation rate h periods into the future, $E(g_{t+h})$ represents the percentage deviation of output from its long-term trend (proxied through linear de-trended capacity utilization) and s_t represents the level of financial stress in the economy (proxied using the IMF FSI dataset) which the RBA can also observe since the financial stress dataset is generated using coincident and lagged inputs. For simplicity I assume that the number of periods that the central bank looks forward h is consistent with standard expectation measures ie. 12 months ahead.

One empirical aim is to examine if equation 4.1B is a somewhat representative structure of how the RBA conducts monetary policy, ie. responds to changes in inflationary and output gap expectations as well as financial stress developments in the economy through the adjustment of its policy rate. A difficulty that arises with this is that the coefficients and constant is fixed in equation 4.1B, when in reality the central bank may adjust their weights towards each variable and their neutral interest rate over time depending on the economic context. This is particularly important in regards to financial stress, since the central bank responds to stress in a non-linear way as the consequences of financial stress to the real economy are typically asymmetric. In light of this, I consider an estimation procedure that allows for the policy response in different regimes or states of financial stress to vary in order to appropriately capture for the non-linearity.

⁸ 2.5% represents the midpoint between the RBA's inflationary target of between 2-3% since 1993.

Lastly, following from Clarida et al (1998) and English et al (2003) which demonstrated that an optimal pre-commitment policy involves some degree of policy inertia when expectations are forward looking, it is assumed that there is a gradual adjustment or ‘smoothing’ of the interest rate where the central bank only removes a fraction $(1 - \lambda)$ of the gap between the current target level r_t^* and its previous nominal interest rate r_{t-1} during the conduct of monetary policy.

$$r_t = (1 - \lambda)r_t^* + \lambda r_{t-1} + \varepsilon_t \quad (4.1C)$$

As examined in Debelle and Cagliarini (2000), the path of short-term interest rates due to monetary policy decisions of most central banks in advanced economies tends to be smooth as changes in policy setting are relatively infrequent and occur in small steps.

There are three possible explanations behind why this may occur in practice. Firstly, as discussed in Woodford (1999), smooth changes in policy rates can be highly effective in communicating the central bank’s intentions to forward looking market participants, allowing them to infer future policy actions and translate them into the long term rate. Secondly, policy-makers may disapprove of frequent reversals in the path of policy interest rates since such behaviour could potentially sabotage public confidence in the monetary authorities and create instability in financial markets (Goodhart, 1999). Lastly, is the argument that interest rate smoothing occurs as policy decisions are made under uncertainty (Brainard, 1967). Since the RBA may have uncertainties over the precise gap of their target variables in real time and the exact impact that changes in the interest rate has on reducing these gaps, their policy decisions will be less aggressive and thus smoother.

To consider interest rate smoothing in both the reduced form and structural VAR representations of the threshold vector auto-regression model, a lag parameter of the policy rate variable will be included, which will be discussed in the following subsection.

4.2 Threshold Vector Autoregression (TVAR)

This thesis utilizes a non-linear approach in order to investigate asymmetric reactions of monetary policy to financial stress. A threshold VAR is a non-linear multivariate system of equations that accounts for non-linearity additively by approximating the non-linear data generating process (DGP) through several regime-dependent data DGPs

which are themselves linear. Subsequently, this can be estimated through ordinary least squares (OLS) where an estimated value for the threshold variable (for example, financial stress) decides the boundaries for each regime (whether an observation is in a state of high or low financial stress) with the coefficients and constant terms of the VAR system being directly specific to each regime.

The system of equations for a reduced form VAR with one threshold and two separate regimes can be represented as follows:

$$Y_t = B_1 + \phi_1(L)Y_t + (B_2 + \phi_2(L)Y_t) J [s_{t-d}^* > \gamma] + \varepsilon_t \quad (4.2A)$$

Where Y_t is a vector of endogenous (stationary) variables containing the differenced policy rate, expected excess inflation, expected output gap and financial stress. J is an indicator function that takes the value of 1 if the financial stress variable s_t at lag order d is higher than the threshold value γ and zero otherwise thus allowing for variation of effects across different regimes whilst implying that dynamics change at time t when the threshold value of financial stress crosses the threshold value at time $t-d$. The delay parameter d was chosen to be 1 period based on the Tsay test⁹. $\phi_1(L)$ and $\phi_2(L)$ are lag polynomial matrices and B_1, B_2 represent the constant terms between different regimes. Lastly ε_t represents the error term, however if we assume heteroskedasticity across the two regimes the system of equations is modified to:

$$Y_t = B_1 + \phi_1(L)Y_t + \varepsilon_{1,t} + (B_2 + \phi_2(L)Y_t + \varepsilon_{2,t}) J [s_{t-d}^* > \gamma] \quad (4.2B)$$

Homoskedasticity is a rather strict assumption in the case of regime-switching models especially for a threshold model which by construction implies that the contemporaneous relationship of shocks between regimes are different thus would lead to potential complications in the identification of the structural relationship between shocks. This is addressed by allowing for heteroskedasticity between regimes.

TVAR models can be classified as a special case of the more general Markov switching VARs (MSVARs) which often impose *exogenous* switches. Originally made popular through Hamilton (1989), Markov-switching models have been applied extensively to

⁹ Tsay suggests to choose the delay parameter d such that:

$$d = \underset{v \in S}{\operatorname{argmax}} F(p, v)$$

where $F(p, v)$ is the F statistic of an auxiliary regression with AR order p and the delay parameter equal to v , and S is a set of values of d to consider (between 1 to 6)

analyze business cycles. In the context of monetary policy and financial stress, the exogeneity assumption of the latent state may not be realistic if it is expected that endogenous movements could lead to regime switches for example interest rate reductions on also reducing financial stress or affecting future output. TVAR models on the other hand allow for endogenous switching which may be more appropriate to capture non-linear dynamics in recurring dichotomous such as cycles of low and high financial stress in the economy. Additionally, for MSVARs the state variable is latent or not observed whilst TVARs explicitly model the endogenous regime-switching process as the variable(s) that cause a regime switch are identified through the choice of the threshold variable. Since this thesis focuses on the monetary policy response to financial stress, the choice of threshold variable will be the IMF FSI.

Although the reduced form VAR assumes that no variable has a *direct* contemporaneous effect on the other variables in the model, there is non-zero correlation between the error terms. This means that the propagation of one structural shock can potentially lead to shocks in the other error terms thus creating contemporaneous movement between all the endogenous variables. Regarding the identification of shocks, the Cholesky decomposition is applied, which results in an upper triangular variance-covariance matrix of residuals in the TVAR. The FSI is ordered first as its behaviour is partly exogenous. Therefore, a FSI shock will affect all other variables contemporaneously however a shock in the other variables will not affect FSI contemporaneously. This is followed by expected excess inflation and the expected output gap. Finally, the policy rate is ordered last meaning that it will respond contemporaneously to changes in the expectation of inflation and the output gap as well as the FSI. Ordering the interest rate last is consistent with discussions from Stock and Watson (2001) on different identifying assumptions of the Taylor rule. However, changing the ordering did not have a significant effect on the results.

The chosen lag length of the TVAR model is one lag determined by the Hannan-Quinn information criteria (HQ) and Bayesian information criteria (BIC), which attaches a larger penalty for model complexity than the AIC. All three likelihood criteria are widely used in time series econometrics for both linear and non-linear models and the AIC and HQ have been shown to have good finite-sample properties in non-linear multi-regime models (Psaradakis et al, 2008). These results are summarized and presented in Appendix A.4.

4.3 Structural Identification

Although the *reduced form* VAR described in 4.2 allows for an appropriate *predictive* estimation of how the RBA responds to different variables in the economy, no direct contemporaneous relationship is assumed as each equation in the VAR is estimated on the *lags* of the endogenous variables. Essentially the contemporaneous effect is captured based on the order of the structural shocks imposed from the Cholesky decomposition.

In comparison, a *structural* VAR allows economic theory to justify the contemporaneous links between the endogenous variables (Sims, 1986) by including identifying assumptions that allow the correlations to be interpreted causally.

A 4 variable VAR with financial stress, expected excess inflation, expected output gap and the policy rate is considered, which is represented in the form of an augmented Taylor rule with policy smoothing and financial stress. The structural identification method used is based on a representation discussed in Stock and Watson (2001) which provides general guidance on constructing structural VARs with Taylor rules. In the first equation of the VAR, financial stress is the dependent variable s_t with lagged values of all other 4 variables as regressors. The second equation for expected inflation π_t then includes the lags of all the other variables *plus* the current financial stress measure. Thirdly, the expected output gap g_t includes lagged values of all other variables as well contemporaneous values of financial stress *and* expected excess inflation. Finally, equation r_t is a representative Taylor rule that considers both lagged and contemporaneous developments in inflation, output gap and financial stress as well as incorporates a lagged parameter of the policy rate in order to account for policy smoothing. These equations are represented algebraically as follows:

Levels SVAR equations:

$$\begin{aligned}
 s_t &= [\alpha_1 \pi_{t-1} + \beta_1 g_{t-1} + \gamma_1 s_{t-1} + \theta_1 r_{t-1}] + \varepsilon_{t,1} \\
 \pi_t &= [\alpha_2 \pi_{t-1} + \beta_2 g_{t-1} + \gamma_2 s_{t-1} + \theta_2 r_{t-1}] + \widetilde{\gamma}_2 s_t + \varepsilon_{t,2} \\
 g_t &= [\alpha_3 \pi_{t-1} + \beta_3 g_{t-1} + \gamma_3 s_{t-1} + \theta_3 r_{t-1}] + \widetilde{\gamma}_3 s_t + \widetilde{\alpha}_3 \pi_t + \varepsilon_{t,3} \\
 r_t &= \widetilde{\alpha}_4 \pi_t + \widetilde{\beta}_4 g_t + \widetilde{\gamma}_4 s_t + \theta_4 r_{t-1} + [\alpha_4 \pi_{t-1} + \beta_4 g_{t-1} + \gamma_4 s_{t-1}] + \varepsilon_{t,4}
 \end{aligned}$$

By defining the following matrices;

$$Y_t = \begin{pmatrix} s_t \\ \pi_t \\ g_t \\ r_t \end{pmatrix} \quad S = \begin{pmatrix} 1 & 0 & 0 & 0 \\ s_{21} & 1 & 0 & 0 \\ s_{31} & s_{31} & 1 & 0 \\ s_{41} & s_{42} & s_{43} & 1 \end{pmatrix} \quad \alpha = \begin{pmatrix} \mu_s \\ \mu_\pi \\ \mu_g \\ \mu_r \end{pmatrix} \quad \Gamma = \begin{pmatrix} \gamma_1 & \alpha_1 & \beta_1 & \theta_1 \\ \gamma_2 & \alpha_2 & \beta_2 & \theta_2 \\ \gamma_3 & \alpha_3 & \beta_3 & \theta_3 \\ \gamma_4 & \alpha_4 & \beta_4 & \theta_4 \end{pmatrix}$$

The structural VAR can then be summarized in matrix notation as:

$$S * Y_t = \alpha + \Gamma Y_{t-1} + \varepsilon_t \quad (4.3A)$$

If S is invertible then equation 4.3A can also be represented as:

$$Y_t = S^{-1}\alpha + S^{-1}\Gamma Y_{t-1} + S^{-1}\varepsilon_t \quad (4.3B)$$

This structural specification however is not directly comparable to the reduced form VAR estimation which utilizes the *differenced* policy rate term rather than the *level* series suggested in the conventional Taylor rule. Additionally, in the reduced form VAR the Taylor rule does not directly enter any of the equations as only lagged variables of the expected excess inflation, expected output gap, financial stress level and policy rate are used to predict how the RBA behaves under particular shock settings.

Alternatively, a differenced version of the Taylor could be obtained through the structural equations by defining r_t and r_{t-1} as follows:

$$\begin{aligned} r_t &= \widetilde{\alpha}_4 \pi_t + \widetilde{\beta}_4 g_t + \widetilde{\gamma}_4 s_t + \theta_4 r_{t-1} + [\alpha_4 \pi_{t-1} + \beta_4 g_{t-1} + \gamma_4 s_{t-1}] + \varepsilon_{t,4} \\ r_{t-1} &= \widetilde{\alpha}_4 \pi_{t-1} + \widetilde{\beta}_4 g_{t-1} + \widetilde{\gamma}_4 s_{t-1} + \theta_4 r_{t-2} + [\alpha_4 \pi_{t-2} + \beta_4 g_{t-2} + \gamma_4 s_{t-2}] + \varepsilon_{t-1,4} \end{aligned}$$

Subtracting r_t from r_{t-1} and defining $v_{t,i}$ such that $v_{t,i} = \varepsilon_{t,i} - \varepsilon_{t-1,i}$ for $i = 1, 2, 3, 4$ the SVAR with the differenced Taylor rule can be obtained:

Differenced SVAR equations:

$$\begin{aligned} \Delta s_t &= [\alpha_1 \Delta \pi_{t-1} + \beta_1 \Delta g_{t-1} + \gamma_1 \Delta s_{t-1} + \theta_1 \Delta r_{t-1}] + v_{t,1} \\ \Delta \pi_t &= [\alpha_2 \Delta \pi_{t-1} + \beta_2 \Delta g_{t-1} + \gamma_2 \Delta s_{t-1} + \theta_2 \Delta r_{t-1}] + \widetilde{\gamma}_2 \Delta s_t + v_{t,2} \\ \Delta g_t &= [\alpha_3 \Delta \pi_{t-1} + \beta_3 \Delta g_{t-1} + \gamma_3 \Delta s_{t-1} + \theta_3 \Delta r_{t-1}] + \widetilde{\gamma}_3 \Delta s_t + \widetilde{\alpha}_3 \Delta \pi_t + v_{t,3} \\ \Delta r_t &= \widetilde{\alpha}_4 \Delta \pi_t + \widetilde{\beta}_4 \Delta g_t + \widetilde{\gamma}_4 \Delta s_t + \theta_4 \Delta r_{t-1} + [\alpha_4 \Delta \pi_{t-1} + \beta_4 \Delta g_{t-1} + \gamma_4 \Delta s_{t-1}] + v_{t,4} \end{aligned}$$

Because results from the differenced model are rather difficult to interpret or compare with previous literature since variables besides the policy rate are *also* differenced in the differenced SVAR specification, I use the *levels* version of the SVAR model for simplicity.

This provides an additional check to confirm how the threshold SVAR model using an augmented Taylor rule with financial stress compares with findings from previous literature that have used more parsimonious representations of the Taylor rule.

4.4 Threshold Estimation and Non-Linearity Tests

The threshold value of the switching variable for the TVAR is estimated endogenously through a grid search over possible values where the grid is trimmed at both an upper and lower bound in order to ensure a sufficient number of observations for estimation in both regimes. Although there are no general guidelines on the choice of trimming size, a level of trimming was selected to ensure at least 35 data points within each regime. The estimated threshold value corresponds to the model that minimizes the determinant of the variance-covariance matrix of estimated residuals, which is analogous to the sum of squared residuals criterion of a univariate model, to maximise the fit of the model.

$$\gamma^* = \arg \min_{\gamma} \log |\Omega_e(\gamma)| \quad (4.4A)$$

Furthermore, to confirm that utilizing a TVAR model over the simpler linear VAR model is indeed meaningful non-linearity tests for each equation of the VAR system are applied.

Because the unknown threshold is not identified under the null hypothesis (Hansen, 1996), standard inference using the Wald test of whether the coefficients of B_2 and $\phi_2(L)Y_t$ are equal to zero cannot be applied, instead a sup-Wald statistic needs to be calculated in order to evaluate the statistical relevance of endogenous thresholds. The sup-Wald statistic of all possible statistics over the grid is represented by W^* .

$$W^* = \sup_{\gamma} W(\gamma) \quad (4.4B)$$

Additionally since γ is not identified under the null hypothesis the distribution of this statistic does not follow a chi-squared distribution. It has been shown however that this

can be accounted for through a transformation that is determined through a conditional probability measure which can be approximated through simulation. The Monte Carlo procedure proposed by Hansen (1997) is utilized to generate the distribution for the sup-Wald statistic for which asymptotic p-values can be derived. A simulation size of 500 replications is used.

The results of the non-linearity tests using financial stress as the threshold variable suggest the Australian economy experienced threshold effects for monetary policymaking in all of the equations of the reduced form VAR system besides the expected output gap, therefore justifying financial stress as an appropriate threshold variable and signalling that non-linear relationships are present within the analysis which coincides with previous theoretical and empirical literature. A full summary of these results are included in Appendix A.5.

4.5 Generalized Impulse Response Functions

As estimated constant and coefficient values are not particularly useful in standard VAR analysis (Sims, 1980) due to collinearity, the majority of the analysis will involve impulse response functions. The benefit of using this approach is that it allows the econometrician to visually observe the ‘response’ of a variable (eg. the change in the policy rate by the central bank) to a certain ‘impulse’ or shock in the econometric system. This provides a statistical representation of how the policymaker might react through the adjustment of their policy rate given hypothetical scenarios such as an increase in inflationary or output gap expectations as well as the level of financial stress in the economy during a specific regime.

Traditionally, impulse response functions assume that the economy stays within their respective regime after an initial shock ruling out endogenous regime-switches that may occur throughout the rest of the forecast horizon. As such, linear VARs are history independent with reactions to shocks being directly proportional to the shock itself making impulse response calculations relatively straightforward as they can be directly obtained from the estimated coefficients due to convenient properties such as symmetry in the sign and size of structural shocks as well as a constant covariance structure. However, since structural shocks in the non-linear TVAR model can lead to switches in regimes, these convenient properties no longer hold. This complication invalidates the method of constructing the impulse responses as simply the path followed by a variable

after an initial shock as there is history *dependence*. As such, it necessitates the computation of generalized impulse response functions (GIRFs) which were developed in Koop et al (1996).

Koop et al (1996) proposes a solution to the issues discussed earlier, defining the non-linear generalized impulse response functions (GIRF) as the “difference between the forecasted paths of variables *with* and *without* a shock to a variable of interest”.

This can be represented as:

$$GIRF_y = (h, \Omega_{t-1}, \varepsilon_t) = E(Y_{t+h}|\Omega_{t-1}, \varepsilon_t) - E(Y_{t+h}|\Omega_{t-1}, \varepsilon_t^0)$$

Where Y_{t+h} is a vector of variables at time horizon h , Ω_{t-1} is the information set available before the time of shock t and ε_t^0 is the stochastic disturbance term at time 0 under a no shock setting. This implies that there is no restriction regarding the symmetry of the shocks in terms of their sizes, because the effect of a ε_t shock depends on the magnitude of the current and subsequent shocks.

In order to get the complete information about the dynamics of the model, the impulse responses have to be simulated for various sizes and signs of the shocks. The steps of the algorithm to compute the GIRFs are summarised as follows:

- i. A history Ω_{t-1} for each variable that comprises of all the lags up to order p in the variables of the VAR is selected based on which particular regime is assumed meaning that a particular realization ξ_{t-1}^r of the threshold variable is drawn randomly based on the regime.
- ii. Shocks are drawn from the cholesky decomposition variance-covariance matrix of the residuals of the estimated VAR model where a joint distribution of shocks is assumed and a k -dimensional vector ε_{t+h}^b is drawn at each horizon (where k represents the number of endogenous variables in the VAR)
- iii. Additionally, the future progression of all variables is simulated from the estimated coefficients for both regimes as well as the shock process for $h+1$ periods conditional on initial conditions thus allowing the model to switch between regimes during the forecast horizon. This is denoted as $Y_{t+h}(\xi_{t-1}^r, \varepsilon_{t+h}^r)$
- iv. Step *iii* is repeated however the shock at $t=0$ is replaced with a shock of size δ_j for the variable j and the corresponding contemporaneous shocks for all the

other variables which is denoted as the $h \times 1$ vector ε_j^* . This particular sequence is defined as $Y_{t+h}(\xi_{t-1}^r, \varepsilon_{t+h}^r, \varepsilon_j^*)$.

- v. Simulation for steps *ii-iv* are repeated R times to obtain an average for the shocks and B times for steps *i-iv* in order to determine an average over the respective regime history. Since this is computationally very intensive, I use a smaller R and B of 300 instead of the 1000 recommended in Koop et al (1996) which is equivalent to 10^9 repetitions. Therefore, the difference between the simulated forecast assuming shock ε_j^* and the forecast without the shock represents the GIRF:

$$GIRF(h, \Omega_{t-1}, \varepsilon_t) = [Y_{t+h}(\xi_{t-1}^r, \varepsilon_{t+h}^r, \varepsilon_j^*) - Y_{t+h}(\xi_{t-1}^r, \varepsilon_{t+h}^r)] / (B \times R)$$

4.6 Confidence Bands for GIRFs

To compute the confidence bands from the GIRFs a bootstrap procedure is required in order to generate the distribution. The following algorithm is used:

- i. Simulated data is generated recursively by utilizing the estimated coefficients and errors from the TVAR structure.
- ii. By employing the *recursive* dataset from step *i*, the regression coefficients of $B_1, B_2, \phi_1(L)$ and $\phi_2(L)$ as well as the error terms are calculated from the TVAR where the threshold value is assumed to align with the estimated value γ .
- iii. Now utilizing the *original* dataset but the coefficients and errors generated from step *ii*, the GIRFs are calculated using the above algorithm from step *v* of section 4.5, for every combination of shocks and initial conditions.
- iv. By repeating steps *i-iii* S number of times ($S=300$) a sample distribution of the GIRFs can be obtained where the upper and lower boundaries of the confidence bands are determined by their respective significance levels. The nearest simulated impulse response observations to the $0.975 \times 300^{\text{th}}$ and $0.025 \times 300^{\text{th}}$ values were then selected to define the 95% confidence band for the GIRFs.

Because the sample size is limited, generating 95% confidence bands for the impulse response functions can be useful in gaining a richer perspective of the RBA response during particular states of the economy rather than be biased by outlying examples. This is particularly useful for the examination of the central bank response to inflation, output and financial stress during the high stress regime as financial stress observations

above the estimated threshold level tend to be more volatile (for example during the 2007-09 crisis period, some observations of FSI were above 7 standard deviations away from their trend value) and scarce thus can benefit from repeated simulations.

The replication size was again reduced during the estimation from 1000 and 500 recommended replications and loops in the confidence band calculation to 300 each respectively. This is due to the problems and difficulties with computational intensity referred to earlier. The cost of using a lower replication size is potentially higher standard errors which lead the confidence bands to become wider. Parallel computing was utilized in order to improve processing speed to allow the confidence bands to be generated within a reasonable timeframe.

4.7 Methodological Limitations

Because a unit root was present in the Australian policy rate series, the data was transformed through differencing. The cost of this transformation is potential informational loss (in particular long term effects), since the levels of the policy rate is removed. Implicitly this assumes that rate adjustments at higher levels of interest (eg. from 7.25% to 7.00% in 2008) are identical to changes during periods where interest is low (eg. 2.75% to 2.5% in 2013). As this thesis is primarily concerned with how monetary policy responds to each of the relevant variables during the short term, the transformed series of the policy rate is employed in the analysis. A potential solution towards preserving the *levels* effect of the policy rate is to include it as a second threshold variable along with the FSI thus creating 4 separate regimes, distinguishing different monetary policy responses during high and low states of the interest rate *and* FSI. Doing this however would be very costly in terms of estimation and statistical power as observations are scarce in the high financial stress regime, thus are unlikely to yield reliable or meaningful estimations.

Additionally, estimation of results also relies on the assumption that the variables and techniques used to proxy expectations of inflation and the output gap are sufficiently suitable. Reasons for why this may not be the case was previously discussed in sections 3.2 and 3.3. This leaves potential for considering additional measures that may improve the fit of the model such as real housing prices from Stapledon (2007) which provides an indication on if housing is overvalued. Since a downturn in the housing sector can have a substantial impact on the level of inflation as well as the output gap, it may have

a non-negligible role in shaping the policymaker's expectations. These developments however may be only be *partially* captured by the data utilized in my model. This is because the weight of importance of housing price movements could potentially be undervalued through the use of consumer inflationary expectations and linear detrended capacity utilization if consumers care less about developments in the housing sector than the RBA.

5 Results

The analysis of the research will be broadly categorized into two main sections. Firstly, in section 5.1 the results of the reduced form TVAR model will be presented, which provides a predictive estimation of how the central bank responds to economic developments including financial stress, expected excess inflation and the expected output gap. This operates as the central analysis used in the thesis. As an additional check, a structural TVAR model which includes an augmented Taylor rule with financial stress is evaluated in section 5.2. This subsection serves as a comparison to previous papers that have investigated more traditional representations of the Taylor rule without financial stress.

The structure of both sections will be summarised as follows. Firstly, the parameter selection and estimated threshold for each model will be briefly discussed. This is followed by analysis of impulse response functions with confidence bands for both regimes of the relevant economic relationships, in particular on if they align with economic intuition and previous literature. Finally, section 5.3 will summarize and discuss the key findings of the results and discuss potential limitations with the research.

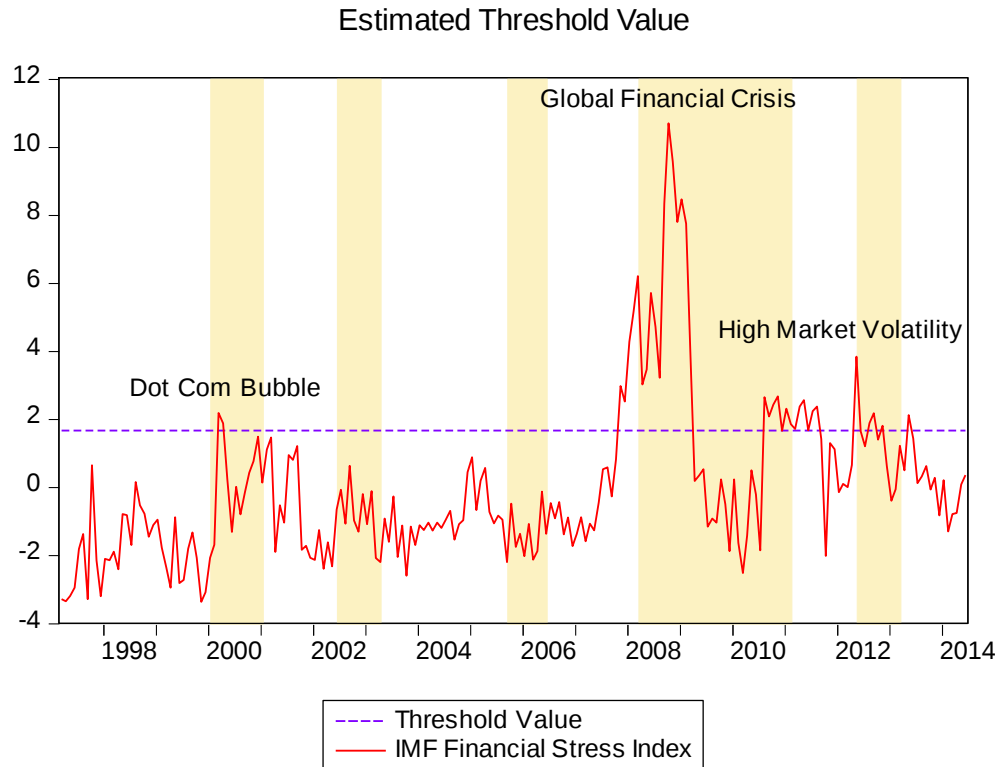
5.1 Reduced Form TVAR

5.1.1 Parameter Selection and Estimated Threshold

The number of lags to use in the reduced form VAR, threshold value and delay lag in the model were simultaneously estimated to maximise fit. A VAR lag and delay length of 1 was chosen. To select the appropriate threshold value to separate which observations belong within the low or high financial stress regimes, 50 grid points were used with a minimum trimming to ensure at least 35 observations in each regime. The grid search then considers various thresholds between -3.4 and 10.7 for the FSI with interval sizes of 0.282, choosing 1.65 as the threshold cut-off. This resulted in 82.2% of the observations belonging in the low financial stress regime and 17.8% of observations belonging in the high financial stress regime. Although this may cause results in the high financial stress regime to be comparatively volatile to the low stress regime, the

threshold value needs to be sufficiently high in order to adequately capture the non-linear aspects of financial stress since it is a focal point of the thesis.

Figure 5.1.1: Threshold Variable – IMF Financial Stress



A threshold value of 1.65 indicates that when the level of financial stress in the economy as estimated by the IMF is greater than 1.65 standard deviations from its trend level at time $t-d$, that observation will be classified as being in the high financial stress regime.

This cut-off level is indicated by the dotted purple line shown above in figure 5.1 and accumulates observations for the high financial stress regime during three broad periods: the 2000 dot com crash, the global financial crisis during 2007-09 and the period between 2010-11 and early 2012 where financial market volatility was historically high due to economic concerns surrounding Europe¹⁰. Cardarelli et al (2011) suggests that observations above 1 have been indicative of past crises which are also demonstrated here by the observations included in the high regime. Therefore, the endogenously determined threshold cut-off in my model provides an appropriate

¹⁰ Previously discussed on pg 20

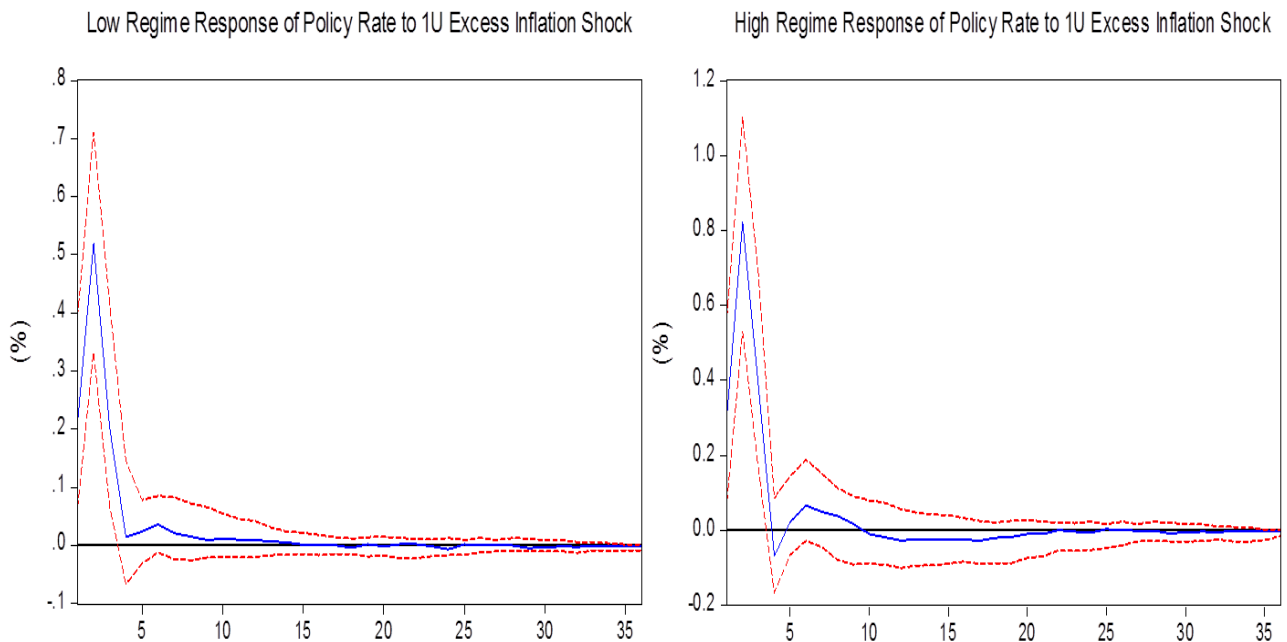
allocation of data points for analysing the non-linear response of monetary policy to developments in financial stress.

5.1.2 Impulse Response Analysis

Each impulse response diagram will span a time horizon of 36 periods or 3 years. Traditionally, the forecast horizon used in impulse responses may be longer however since the differenced policy rate series is used in the reduced form TVAR, the period length chosen allows a sufficient summary of the policymaker's reaction to each particular shock. All shocks generated are in terms of one unit changes in both the low and high stress regimes which provides a statistical representation of the extent policymakers adjust the short term interest rate (in terms of percentages) as a reaction to a 1% or 1 unit (for FSI) increase to each corresponding variable.

Response of Policy Rate to Shocks in Excess Inflation

Standard economic theory and the Taylor rule suggests that a one percent increase in inflation from its target should be matched with a more than one percent increase in the policy rate.



As observed, the reaction of the policy rate to a positive shock in expected inflation is similar in terms of direction in both the low and high financial stress regimes, where the response is positive during the initial phases of the forecast horizon. In terms of sign, the results are consistent with economic literature as an increase in interest rates all else

equal would have a contractionary impact on the economy, thus lowering future inflationary pressures and closing the inflation gap from its target.

In terms of magnitude, for the low regime response the results show a series of abrupt increases in the policy rate over the first three periods (0.21%, 0.52%, 0.20%). This sums to a cumulative response of a 93 basis point policy rate increase over the opening three periods after a 1% positive shock in expected excess inflation is introduced.

Surprisingly however, the policymaker's response to increases in expected excess inflation is higher in the higher stress regime than the lower stress regime. This may initially seem counterintuitive as typically the central banker may be less concerned with addressing inflationary pressures when financial stress is high and economic prospects are dampened. However, Lee et al (2013) which employed a time-varying estimation of the meta Taylor rule for Australia, record a similar effect where the inflation coefficient was non-trivially higher from 2009-10 which coincides with our high stress regime. The estimated cumulative interest rate response to a one unit shock in expected excess inflation in the high regime by the third period is 151 basis points which further increases to 163 basis points by the eighth period.

There are two possible explanations behind why the policy response to inflation was estimated to be stronger in the high stress regime. Firstly, it could be due to the capturing of both the increase in excess inflation *and* the switch from the low to high stress regime during estimation. This may have also indirectly influenced the estimated policy response to positive shocks in FSI to be more negative in the high stress regime as well which will be discussed later. Secondly, it could be due to differences in the smoothing parameter between the low and high stress regime. As policy adjustments are typically infrequent especially during more stable economic periods (low financial stress), there may be lower variation in the low financial stress state compared to the high financial stress state thus explaining why the inflationary response during the low regime was relatively less sensitive.

Table 5.1.2: Policy Smoothing Between Regimes

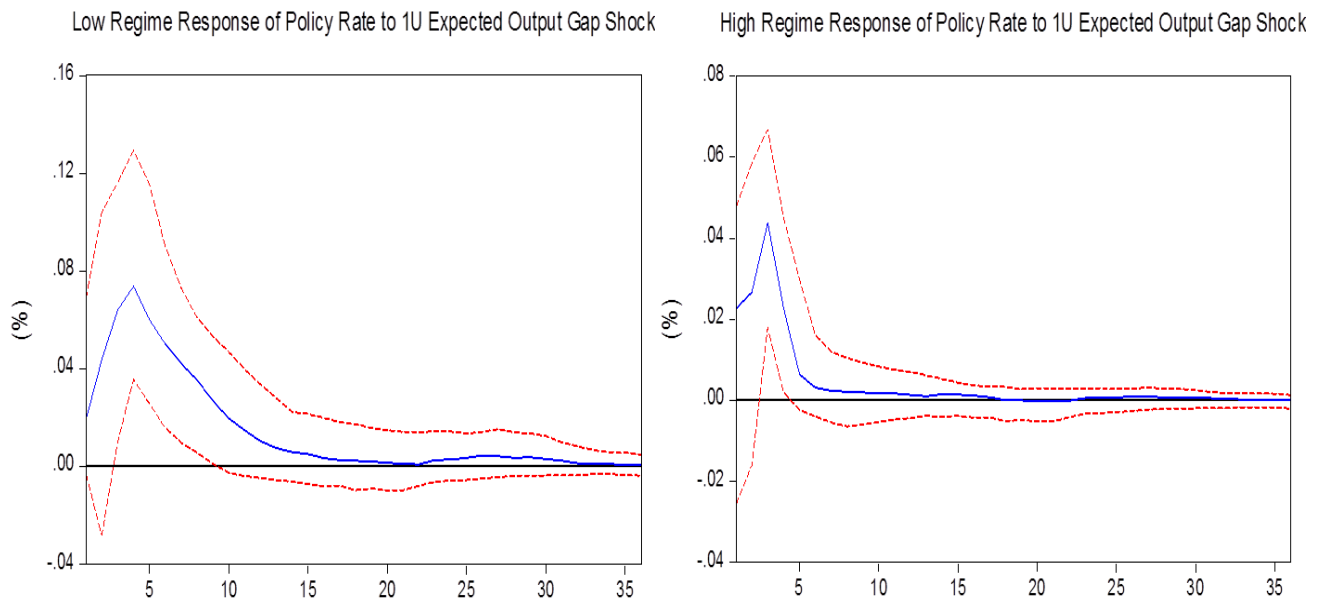
Regime	Number of Changes in Policy Rate	Total Observations	Proportion (Δ s)
Low	52	171	30.41%
High	20	37	54.05%

Based on the threshold cut-off value of 1.65, the above table shows that the degree of policy smoothing is significantly higher in the low stress regime (69.59%) where only 30.41% of observations for the RBA overnight policy rate varied between periods compared to 54.05% of observations in the high stress regime. Additionally, due to outlying observations in the GFC, the average and median of the FSI was 3.88 and 2.64 in the high stress state compared to -0.85 and -0.97 in the low regime which may cause some amplification of the estimation of the central banker's response to financial instability during the high stress regime.

There are three potential methods to analyse the implications of the discussed problems. Firstly, one could construct the cumulative policy response to both excess inflation *and* financial stress shocks for interpretation in an attempt to cancel out the counter directional amplifying bias between both effects. However, this may not be particularly useful as we are interested in analysing how the RBA responds to financial stress shocks when all other relevant conditions are isolated (such as inflation and the output gap). Additionally, an alternative econometric approach is to redefine the dataset into two additional regimes where only observations that have changed are included. This therefore removes the effect of policy smoothing when estimation is performed on the 52 and 20 observations in the low and high regimes. This issue with this however, is scarcity in sample size therefore may not yield reliable estimations.

As a large number of observations after the initiation of the financial crisis in Australia contained policy changes, many of which were large due to outlying levels of financial stress, I aim to obtain consistency in the variation between policy smoothing in my robustness checks using a subsample of my data from 1997M3 to 2008M8. This will be evaluated and discussed in section 6.3.

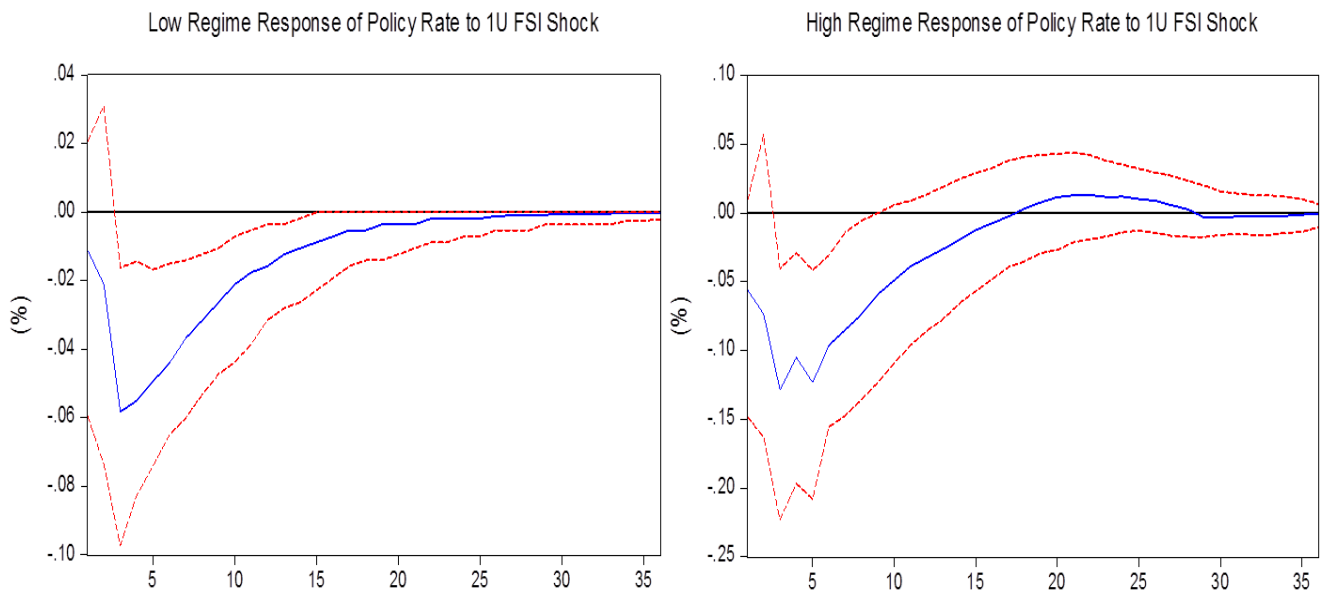
Response of Policy Rate to Shocks in Expected Output Gap



In regards to the policy response of 1 unit positive shocks in the expected output gap, the results align with economic intuition. The estimated policy response during both the low and high stress regimes to a positive shock in expected output gap (expansionary gap) is to increase the policy rate, which intends to reduce the size of the output gap. In the low regime response, the estimated policy reaction is positive and relatively persistent. This suggests that the central bank responds to the output gap by gradually adjusting rates, which contrasts to the shape of the previous IRFs on inflationary shocks which showed a more immediate and fast acting response. Most interest rate changes are implemented by the fourth period, which accumulates to an increase of 21 basis points, which further increases to 43 basis points by the tenth period.

The confidence bands are considerably wide in the high regime estimation due to high standard errors. The estimated effect was also quite negligible (a 0.12% response by the fourth period) which illustrates that the policymaker is not particularly concerned with closing an expansionary gap during the high stress regime. Additionally, the estimated reaction is also sharper and less persistent than the low regime response.

Response of Policy Rate to Shocks in Financial Stress



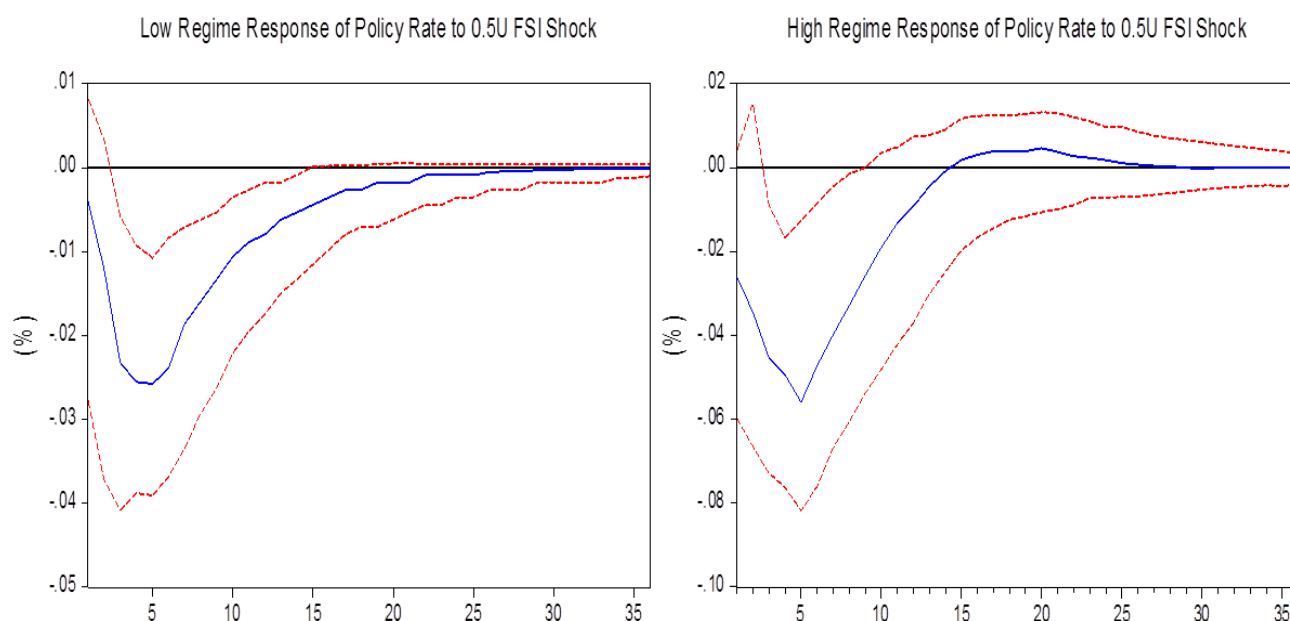
In regards to financial stress, the results show that the policy response to increases in FSI during both the low and high stress regimes is to reduce interest rates. This is generally consistent with previous literature from Baxa et al (2013) and Taylor's recommendation to reduce policy rates to increases in credit spreads (which are included in the FSI measure). In the low regime, this reduction was estimated to be -0.19% by the fifth period, increasing to -0.35% by the tenth period for an increase of FSI by one unit.

Unsurprisingly, the reduction in interest rates is significantly greater when financial stress increases conditional on an already high level being present. The estimated cumulative reduction in policy rates reached -0.44% by the fifth period and -0.79% by the tenth period. However, the estimated response after the 17th period begins to enter the positive region, although was not statistically significant. This suggests the possibility of policy overshooting where the RBA decides that they had cut rates by more than intended in the future which is realistic in a setting where the implications of abnormally high levels of financial stress which are historically rare, are uncertain.

In terms of relevance, the estimated policy response to financial stress in the high regime yields a similar level of magnitude as the response to shocks in the level of inflation which indicates that developments in financial stress is a significant concern for policymakers. This suggests that during a state of high financial instability, increases in the level of financial stress could indicate that the central bank will reduce

the short term interest rate over subsequent periods in a response to combat the negative economic implications of higher financial stress, such as inefficiency in financial intermediation and reduced future output due to bank deleveraging.

However, an additional concern is that a one unit increase in FSI is a substantial shock that may potentially cause a regime switch during the calculation of the GIRFs¹¹. The re-estimated policy reactions to the introduction a 0.5 unit positive shock in FSI are displayed below.



For the low regime, the estimated cumulative policy rate reduction was estimated to be -0.07% by the fifth period, increasing to -0.14% by the tenth period. Compared to the previous results using a 1 unit positive shock, the magnitude have decreased by more than a half which suggests that the previous 1 unit sized shock may have led to endogenous regime switching over the forecast horizon.

For the high regime however the estimated cumulative policy reaction to a 0.5 unit increase in FSI was -0.21% by the fifth period and -0.39% by the tenth period which is comparable to the previously estimated impulse responses under a 1 unit FSI shock after adjusting for scaling. This result is intuitive as switches from the high to low regime are less likely to occur given an increase in the switching variable.

¹¹ Empirical probabilities of regime switching are provided in Appendix C

5.2 Structural TVAR

5.2.1 Parameter Selection and Estimated Threshold

Although the AIC, SIC and HQ criterion identify various optimal lag lengths between 1 and 3, a lag length of 1 is explicitly selected based on the structural model outlined in section 4.3. Additionally, an estimated delay length of 1 was chosen. The threshold cut-off value changed a negligible amount from 1.65 to 1.68 due to reduced degrees of freedom in the structural VAR. The allocation of observations between the two regimes remained reasonably consistent, with 83.1% of the observations belonging in the low financial stress regime and 16.9% of observations belonging in the high financial stress regime.

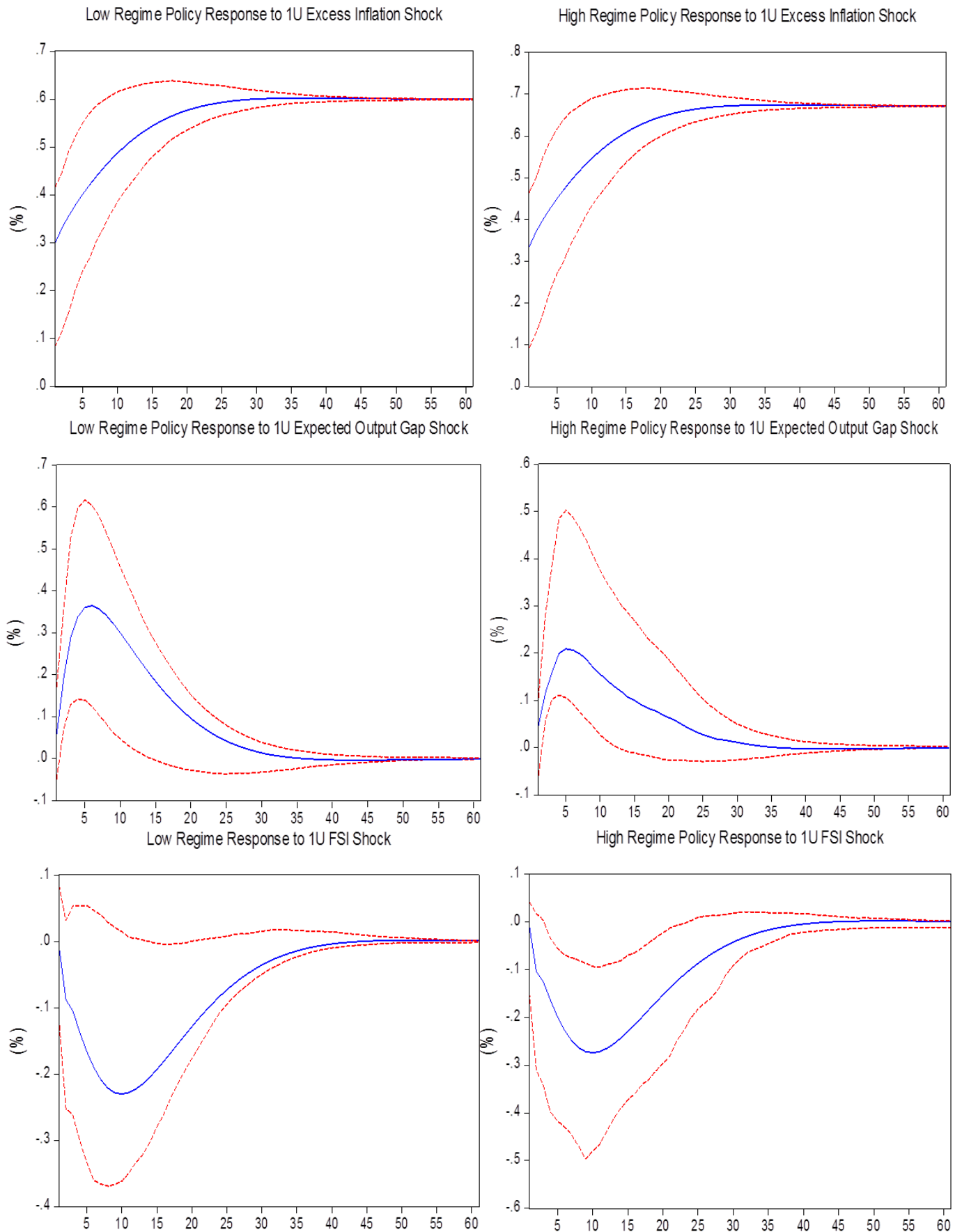
5.2.2 Impulse Response Analysis

Since the structural TVAR uses the *level* series of the policy rate, the forecast horizon of the impulse responses is increased from 36 to 60 periods to account for persistence. Although the structural VAR estimated follows a similar construction technique to Stock and Watson (2001), the variables used, sampling period and country of study are all different to my model. The main divergences are that their model does *not* include financial stress in any of their equations or within the Taylor rule and additionally they use the unemployment rate instead of the expected output gap measure.

In terms of the estimated signs for each of the estimated IRFs, they align with economic intuition and the results from the reduced form TVAR model. The sign of the policy response to a one unit shock in expected output gap and excess inflation was positive in both regimes which demonstrate that the RBA will increase interest rates in a reaction to unexpected expansionary gaps and inflationary pressures. Furthermore, the estimated policy response to increases in FSI is negative, which consolidates previous findings.

In terms of magnitude for the estimated response to increases in expected excess inflation, my IRF estimations were larger than Stock and Watson (2001). Direct comparison however is challenging as they used the unemployment rate which was estimated to be substantial. The unemployment rate can be thought of as a proxy for the expected output gap measure, however in terms of scale it may be vastly different to linear de-trended capacity utilization. Additionally, their research was focused on the US economy.

Figure 5.2.2: Impulse Response Functions of Structural Threshold VAR



In comparison to Baxa et al (2013) which assesses a time-varying backward looking model with a Taylor rule including financial stress, my results for the output gap and financial stress measures are generally consistent with their findings for Australia. They however report a stronger policy rate relationship with inflation than my estimates shown which could be due to differences in my model specifications and sampling period used.

5.3 Key Findings and Limitations

The results of the impulse response functions in the TVAR model suggest that policymakers do evaluate developments in financial stress in the economy when conducting monetary policy. The overall estimated response to a one unit increase in FSI during the low regime was to decrease policy rates by 0.2% during the first five periods, which is around a typical interest rate decision adjustment size of 25 basis points. This is comparable albeit smaller in terms of magnitude to the RBA's sensitivity to developments in the expected output gap. However, the estimated policymaker response to increases in FSI was significantly large during the high financial stress regime with around a 0.5% reduction in the policy rate by the fifth period.

A potential source driving this result could be due to changes in the size of the smoothing parameter between the two regimes as well as outlying observations in the high regime state which is of a small sample size. Therefore additional checks are conducted in the following section in order to examine the sensitivity and robustness of these results.

6 Robustness Checks

Various robustness checks were performed on the reduced form TVAR model in order to assess the sensitivity of the results to alternative estimation methods. Because the reduced form TVAR model uses the *differenced* interest rate series as the response variable, rather than the *level* interest rate series in the structural model, the reduced form TVAR is likely to be more perceptive to changes. Three robustness checks were performed involving modifying the degree of trimming used in the model, implications of using an alternative interest rate measure that partially considers unconventional monetary policies and using a subsample that excludes the global financial crisis period.

6.1 Threshold Sensitivity

The threshold estimation procedure is generally sensitive to the amount of trimming selected. Because the threshold cut-off value defines which observations fall under the low or high regimes, a different level of trimming could potentially prompt non-negligible adjustments to the estimated impulse response functions.

However, to coordinate with the aims of the thesis, a sufficiently high threshold value of FSI (at least above 1) is required in order to appropriately capture the non-linear components during the modelling process (ie. to correctly identify and separate low and high financial stress regimes in reality). Therefore trimming sizes of 25-30% are likely to be not applicable as some observations in the high regime will not be synonymous with a financial crisis even though they would ensure a greater number of observations into the high stress regime which would improve modelling accuracy.

Table 6.1A: Estimated threshold value at various trim sizes

Trimming (%)	Endogenously Determined Threshold (FSI)
5	3.52
10	2.31
15	1.86
17 ¹²	1.65
20	1.38
25	0.78
30	0.34

Table 6.1B: Cumulative RBA Response to 1U Increase in FSI by Periods 5/10

Threshold Cut-off	Low Regime	High Regime
2.31	-0.29/-0.46	-0.47/-0.84
1.86	-0.25/-0.43	-0.46/0.81
1.65	-0.19/-0.35	-0.44/-0.79
1.38	-0.17/-0.32	-0.40/-0.73
0.78	-0.15/-0.29	-0.31/-0.54

Table 6.1B shows the estimated cumulative RBA response to a 1U shock in financial stress in both the low and high regimes under various threshold cut-off settings with the baseline model highlighted in bold. Generally, the model results of the policy response to FSI are not particularly sensitive to further reductions in trimming size as the default setting of at least 35 observations has already appropriately captured the high financial stress regime. However, increases in the trimming size to 20-25% to expand the number of observations in the high financial stress regime, do lead to a non-trivial reduction in the size of interest rate cuts in the high financial stress regime. Additionally, the strength of non-linearity decreases as the gap between the low and high regimes closes after decreases in the threshold value. These results suggest that the model may be sensitive to particular specifications chosen in the study.

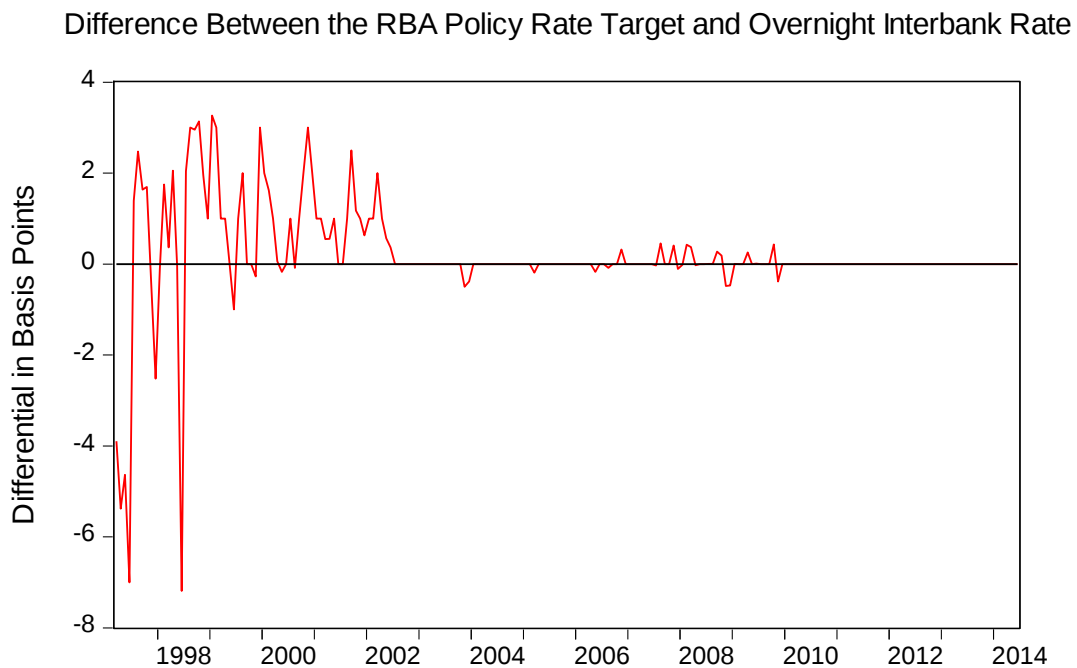
¹² This is the trimming level chosen to obtain the main modelling results. 16.9% was chosen to ensure at least 35 observations in each regime.

6.2 Interbank Rate

Although the manipulation of the policy rate was the main instrument used by central banks during the 2008-09 financial crisis, other unconventional measures were also considered and implemented during this period. Borio and Disyayat (2009) classifies unconventional policies as ones that can *'affect the central bank's balance sheet size and composition that are insulated away from interest rate policy'*. A prominent example is quantitative easing, which aims at injecting additional liquidity into the system and was a widely used strategy in the United States as they reached the zero lower bound.

As a robustness check the interbank interest rate is compared with the RBA policy rate target since the former measure allows more attention for unconventional policies as the liquidity conditions in the interbank market are considered.

Figure 6.2: RBA Policy Rate and Interbank Rate Differential



Based on the estimated differentials¹³ between the two interest rates, no substantial gaps were observed besides the beginning of the sampling period between 1997-2002 where the average absolute differential was only 3 basis points. Additionally, there were negligible deviations between the various rates during the financial crisis period which

¹³ Calculated as the RBA policy rate minus the overnight interbank rate between the sample period of 1997M3 to 2014M6

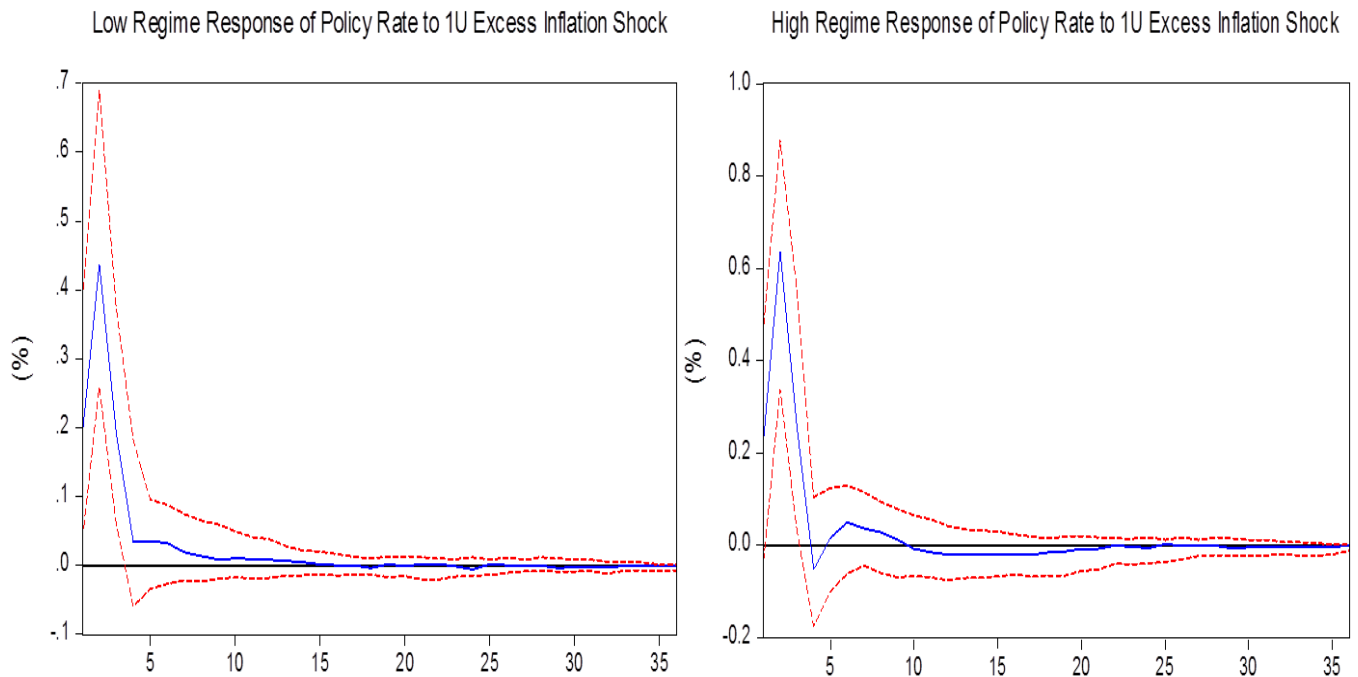
suggests that re-estimation of results using the interbank rate would lead to very insignificant differences to the previous estimations with the RBA policy rate. Therefore, this indicates that the model is robust to alternative interest rate measures used.

6.3 Alternative Sampling Period

The period preceding 2008M9 is significantly less volatile than the stages following it both in terms of the size of financial stress in the economy as well as the magnitude of movements in the policy rate. The severity of the financial crisis reached a boiling point on the 15th of September 2008, when the US government allowed the investment bank Lehman Brothers to go bankrupt. This was marked by a spike in the Australian FSI to 8.3 standard deviations above its trend value during the next month. As discussed in previous sections, this particularly erratic period could have a significant impact on the estimation of the impulse responses especially during the high stress regime as the RBA reaction to previous timings of high financial stress (above the threshold value) such as early 2000, late 2007 and early 2008, were comparatively benign.

In consideration of this, a robustness check using a sub sample between 1997M3 to 2008M8 was estimated to observe any differentiating characteristics in the impulse response functions. Because this shorter sample reduced the number of observations from 208 to 138, the minimum number of observations per regime was also reduced from 35 to 23 observations to maintain a consistent level of trimming. This resulted in a significantly lower estimated threshold value of 0.55 compared to 1.65 as the majority of observations above a FSI level of 1.65, were found in the period following the propagation of the GFC. Ideally, comparative consistency requires a level of trimming that endogenously estimates an identical threshold value in the subsample to the full sample value to compare differences in policy responses to various variables of interest prior and after the financial crisis. However, this was not empirically possible due to a lack of FSI observations above 1.65 in the subsample.

Response of Policy Rate to Shocks in Excess Inflation

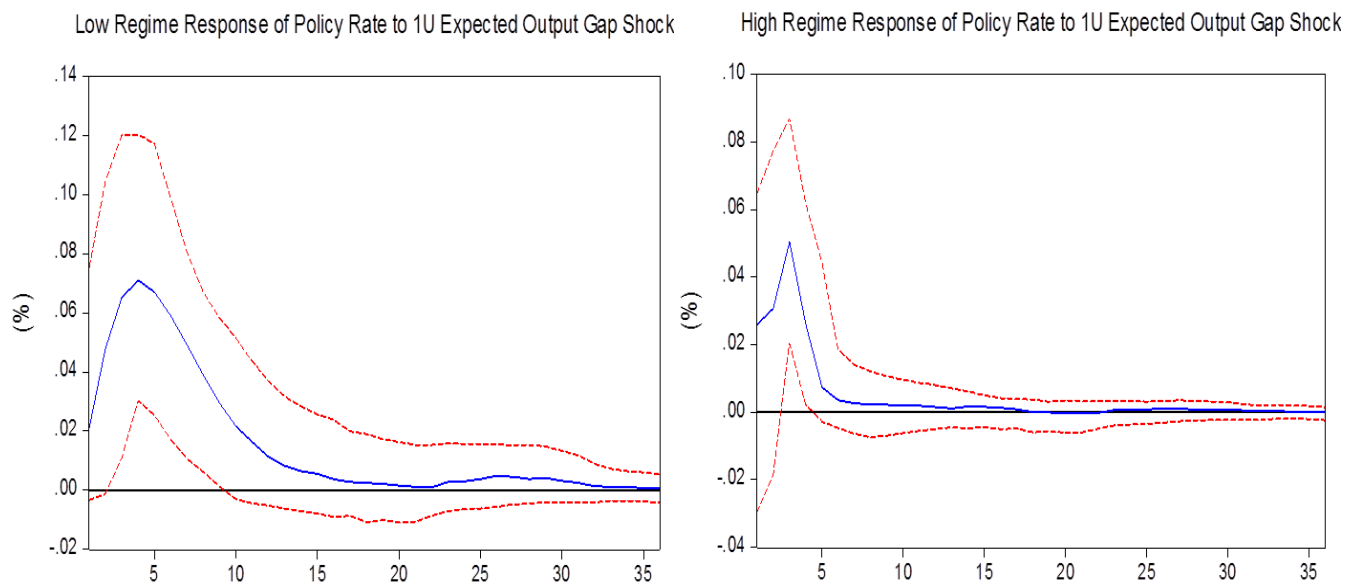


Using the shortened sample, the policy response to a one unit shock in excess inflation becomes reasonably consistent across both the low and high regimes. This provides some evidence that the previous discrepancy between the low and high regime IRFs using the full sampling period may have been biased by the 2008-09 financial crisis period. This could be due to an evaporation of the size of the smoothing parameter (Lee et al, 2013) as policymakers quickly adjusted rates in response to the prevailing economic crisis. If this hypothesis is true, it could lead our previous estimations in the low regime to suffer from bias due to a lack of variation in the dependent variable.

Based on the estimated IRFs using the subsample, it suggests that during the low regime the RBA adjusts by increasing policy rates to a cumulative 82 basis points by period 3 which is 11 basis points smaller than the IRF estimation using the full sample. Additionally, in the high regime the estimated cumulative response by period 3 was 112 basis points compared to 151 from using the full sample.

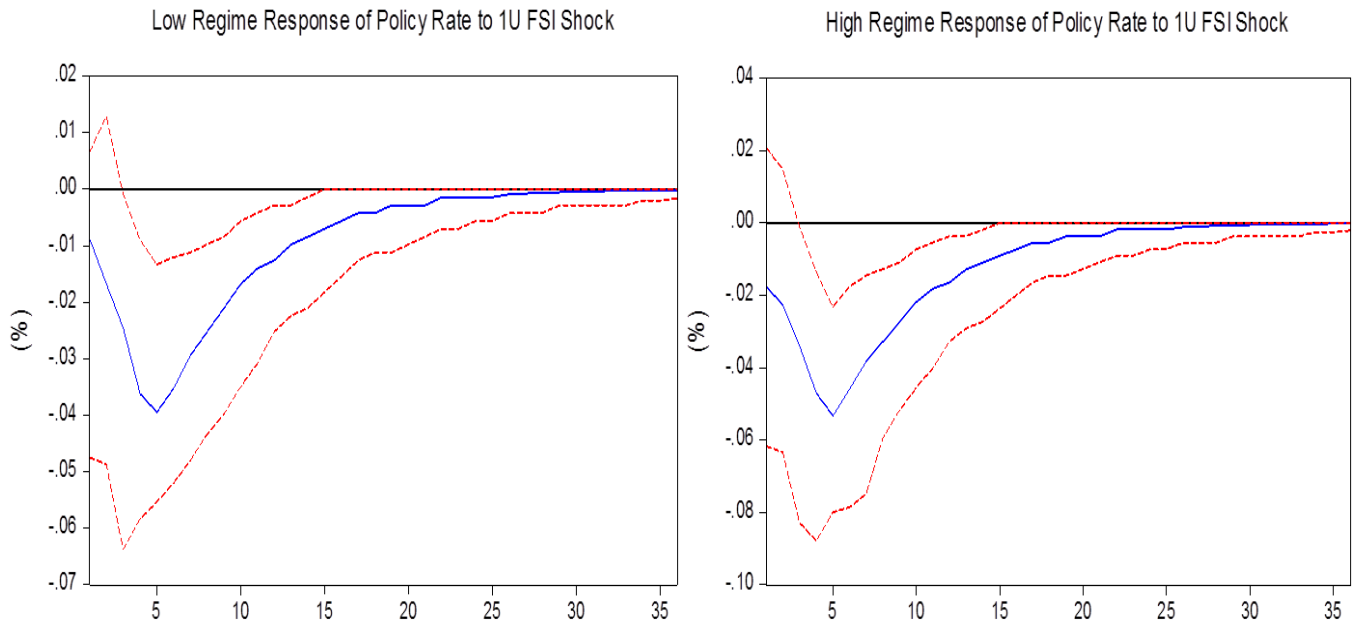
Using the subsample, the estimated IRFs suggest that the RBA is relatively consistent with its process of inflation targeting regardless of the level of financial stress in the economy.

Response of Policy Rate to Shocks in Expected Output Gap



The estimated RBA response to shocks in expected output gap using the subsample is generally homogenous with the full sample results in both the low and high financial stress regimes. The low regime estimated near identical cumulative responses at period four, with the discrepancy increasing to 4 basis points by period ten. Additionally, the high regime estimated a cumulative positive response of 13 basis points compared to 12 from using the full dataset. These results suggest that the central bank is generally insensitive to states of financial stress when conducting monetary policy in relation to deviations in expected output

Response of Policy Rate to Shocks in FSI



Although the generated impulse responses using the shortened sample are not directly comparable to the results from using the full sample as the endogenously determined threshold value had decreased substantially from 1.65 to 0.55, the above results do show that non-linearity may perhaps not be appropriately accounted for using this diminished sampling period.

This could be due to several reasons. Firstly, it may be caused by a lack of significant variation in policy rate movements before the financial crisis even during periods when financial stress is above normal; therefore the two regimes look consistent. Secondly, due to the threshold cut-off value being very low, there could be an oversupply of observations defined to belong in the high stress regime even though in reality they signify periods of normal levels of financial stress thus biasing the size of the estimated response in the high regime upwards. Furthermore, this may suggest that there is the possibility that a third regime, the financial crisis regime, which may govern the dynamics of the data. Because that period is extremely volatile, it could have partially affected the previous results by overstating the value of observations that just exceed the threshold cut-off value in the full sample.

In the subsample evaluation, the policy response to financial stress is significantly lower. In the low regime the estimated accumulative policy response to a 1 unit increase in FSI was -0.12% in period 5 and -0.25% by period 10 compared to -0.19%

and -0.35% respectively using the full sample data. In the high regime the estimated accumulative policy response to a 1 unit increase in FSI was -0.17% in period 5 and -0.34% by period 10 compared to -0.44% and -0.79% respectively using the full sample data which are substantial differences.

6.4 Summary of Robustness Checks

Based on the various robustness checks used, it is revealed that the model is significantly impacted by observations after the propagation of the financial crisis in Australia. The effects are especially influential in the estimated central bank responses to inflation and financial stress. In particular, the estimated negative response of the RBA to increases in financial stress in the high regime becomes consistent in terms of magnitude with the low regime, once the outlying period after 2008 has been removed. This suggests that the dynamics of monetary policy is complicated and a two regime single threshold VAR model may be insufficient in capturing all the underlying factors behind RBA interest rate decisions in the consideration of financial instability using the full sample dataset.

To potentially address this problem additional regimes to capture periods of normal, medium-high and very high financial stress may be considered. This is because although financial stress has been measured to be high (above the threshold value of 1.65) in other periods besides 2008-09, the nature and response to the global financial crisis is a unique and particular case and cannot be compared in terms of magnitude to any other economic debacles during the entire sampling period of 1997-2014. Therefore the policymaker's estimated response during the financial crisis period could be imagined as a separate regime on itself. Additionally, a time-varying estimation could also be considered in order to capture changes in monetary policy over time in particular to financial stress. However a concern with these possible extensions is degrees of freedom, which was scarce as a limited sample size between 1997-2014 and non-linear estimation technique was used. Therefore caution is advised in order to preserve model parsimony at the cost of a less dynamically rich representation of how the RBA behaves in light of periods of financial stress.

7 Conclusion

7.1 Discussion of Results

This thesis provides an empirical examination of whether the RBA responds to developments in financial vulnerability after the forecasting information of financial stress is partially accounted for using a forward looking monetary policy framework. Based on a single threshold TVAR model with two regimes, I find that the central bank responds negatively to increases in financial stress by reducing their policy rate. This effect however is amplified during the high financial stress regime, which aligns with previous literature that suggests a non-linear relationship between monetary policy and adverse developments in the financial system.

Because the GFC is an outlying example both in terms of policy reaction and the magnitude of financial stress, it had a significant impact on the estimation of the threshold value which affects the results. However, to appropriately investigate the non-linear relationship between the low and high financial stress regimes a significantly high threshold cut-off value must be determined¹⁴. By excluding the GFC period, very few observations appropriately categorize as periods of significant financial instability, therefore the non-linearity between regimes could not be clearly identified.

Additionally, another key caveat is that the regime may change after an initial shock when using generalized impulse responses which affected some of the results. In regards to this, possible alternatives include using impulse responses with fixed regimes or introducing shocks of a smaller unit size. However, doing so may not necessarily provide an accurate estimation of the non-linear effect of financial stress developments on the conduct of monetary policy. Overall, the results suggest that the RBA responds to significant increases in financial stress by reducing policy rates. However, the estimated magnitude was small and non-linearity between regimes becomes inconclusive after the GFC period was removed.

¹⁴ Based on Cardarelli et al (2011)

7.2 Concluding Remarks

The results indicate that increases in financial stress have a statistically significant *negative* impact on the RBA policy rate. This relationship also holds in the low financial stress regime, which does not support the overall hypothesis that the RBA follows a ‘leaning against the wind’ approach by increasing rates in a response to developments in financial instability. However, the magnitude of this effect was found to be sensitive under various robustness checks. Because observations that appropriately identify durations of financial turmoil are relatively scarce, the choice of trimming used can have a substantial impact on the estimated threshold level which affects the results. Furthermore, there is also substantial clustering in high financial stress observations from 2008-10. If this sample period is removed the non-linearity between estimated impulse responses in the low and high stress regimes subsequently breaks down. This demonstrates that the RBA response during the GFC period may be a unique case, which is difficult to separately capture in a model as observations are limited.

Due to these complications it is problematic to reliably estimate the size of how the RBA responds to financial stress developments as their perspectives may evolve over time. In particular during high financial stress regimes where there is limited degrees of freedom. This reveals that research into the effects of financial crises is both challenging and difficult. Introducing a third regime to classify very high financial stress states could potentially account for the effect of the GFC and may be considered in further research into this area. Moreover, additional investigation into which individual components in the FSI are responsible for this estimated negative effect may provide a richer understanding towards monetary policy.

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A: Data and Empirical Tests

A.0 Data Used for the Econometric Analysis

	Data Length	Source
RBA Policy Rate	1990M8 – 2014M8	RBA
Interbank Overnight Rate	1976M5 – 2014M8	RBA
MI Consumer Inflation Expectations	1993M6 – 2014M6	Datastream
NAB Capacity Utilization	1997M3 - 2014M9	Datastream
IMF Financial Stress Index	1983M6 – 2014M6	IMF*

Due to constraining factors, my sample period covers only between 1997M3 and 2014M6 which provides 208 total observations.

* This extended dataset is currently not made public on the IMF website and is primarily used for internal research. It was obtained from Angela Espiritu who is an economist from the IMF and currently manages this dataset. The most recent publically available version of the dataset was last updated in 2010 with the sample ending at 2009M5.

A.1 Unit Root Tests

The *Augmented Dickey Fuller* and *Elliot-Rootenberg and Stock* unit root tests were used on each of our data series with the lag length selected based on the Akaike information criterion with no intercept or trend in the equation.

	ADF Test Statistic	P-Value	DF-GLS Statistic	P-Value
Policy Rate	-1.091	0.248	4.613	0.125
Expected Inflation	0.035	0.693	0.197	0.001
Expected Output Gap	-2.618	0.009	2.935	0.039
FSI	-4.413	0.000	2.207	0.019
Excess Inflation	-14.39	0.000	0.197	0.001
Differenced Rate	-5.491	0.000	0.550	0.004

Note: Excess inflation is calculated based on the expected inflation minus a target rate of 2.5%. The expected output gap is based on the rolling window linear de-trending method for capacity utilization described in section 3.2.

A.2 Structural Break Tests

The *Quandt-Andrews* structural break test was conducted with the coefficient covariance matrix based on HAC (Newey West) standard errors and 15% observation trimming to test for stability in each of our data series.

	LR F-Statistic	P-Value	Break Date (4)	FSI at (4)
Policy Rate	244.134	0.000	2009M1	8.449
Excess Inflation	0.789	0.999	-	-
Expected Output Gap	-15.999	0.002	2008M5	3.441

The break in the policy rate roughly coincides with the subsequent peaks in FSI during the late 2008 and early 2009 period. No structural break was found in the inflation measure.

A.3 Correlation Matrix

	Excess Inflation	Expected Output Gap	FSI
Policy Rate	-0.069	0.299	0.157
Excess Inflation	1	-0.0003	-0.139
Expected Output Gap	-0.0003	1	-0.327
FSI	-0.139	-0.327	1

A.4 Lag Selection

Reduced Form Model:

Included Lags	Log Likelihood	AIC	BIC	HQ
0	-638.22	6.38	6.45	6.41
1	-384.48	4.02	4.34*	4.11*
2	-358.95	3.84	4.41	4.14
3	-342.48	3.82*	4.67	4.18
4	-331.80	3.85	4.96	4.30
5	-322.74	3.99	5.21	4.48

Structural Model:

Included Lags	Log Likelihood	AIC	BIC	HQ
0	-1023.05	10.12	10.19	10.15
1	-405.69	4.18	4.42*	4.32
2	-369.40	3.92	4.45	4.10*
3	-345.79	3.86*	4.66	4.16
4	-335.56	3.88	4.96	4.28
5	-327.16	3.96	5.29	4.45

A.5 Non Linearity Test

Asymptotic p-values for sup-Wald statistics using FSI as the threshold variable:

Equation	p-value
Expected Excess Inflation	0.009
Expected Output Gap	0.116
IMF Financial Stress Index	0.003

A.6 Cumulative Impulse Responses

Full sample – Cumulative policy response to 1 unit sized shocks

Low Regime

Period	Shock: INF	Shock: GAP	Shock: FSI
3	0.93%	0.13%	-0.09%
5	0.97%	0.26%	-0.19%
10	1.06%	0.43%	-0.35%

High Regime

Period	Shock: INF	Shock: GAP	Shock: FSI
3	1.51%	0.09%	-0.25%
5	1.55%	0.12%	-0.44%
10	1.62%	0.13%	-0.79%

B: IMF Financial Stress Index

To calculate the IMF Financial Stress Index seven variables were combined to source instability propagating from the banking sector, securities and foreign exchange markets to broadly summarize the overall level of financial stress in the economy. Their respective calculations and motivations are briefly described below.

1. Banking Sector:

- A. The *banking-sector beta* captures the correlation between the returns of the banking stock index compared to the overall stock market index using the standard capital asset pricing model (CAPM) calculation defined as:

$$\beta_{i,t} = \frac{COV(r_{i,t}^M, r_{i,t}^B)}{\sigma_{i,M}^2},$$

Where r represents the year-over-year banking or stock market returns computed over a 12-month rolling window. In line with CAPM, a beta greater than 1 indicates that banking stocks move more than proportionately than the overall stock market alluding to increased risk in the banking sector. To better capture banking-related

financial stress, the banking beta was recorded as a non-zero value only during periods when returns are negative to focus on adverse shocks to banks.

- B. The *inverted term spread* is defined as the government short-term rate minus government long-term rate. Since banks generate income by intermediating short-term liabilities (deposits) into longer term assets (loans), a negative term spread suggests that bank profitability is jeopardized.
- C. The *TED spread* is defined as the 3-month LIBOR or commercial paper rate minus the government short-term rate which captures the premium banks charge each other which is a proxy for counterparty risk.

2. Securities Market:

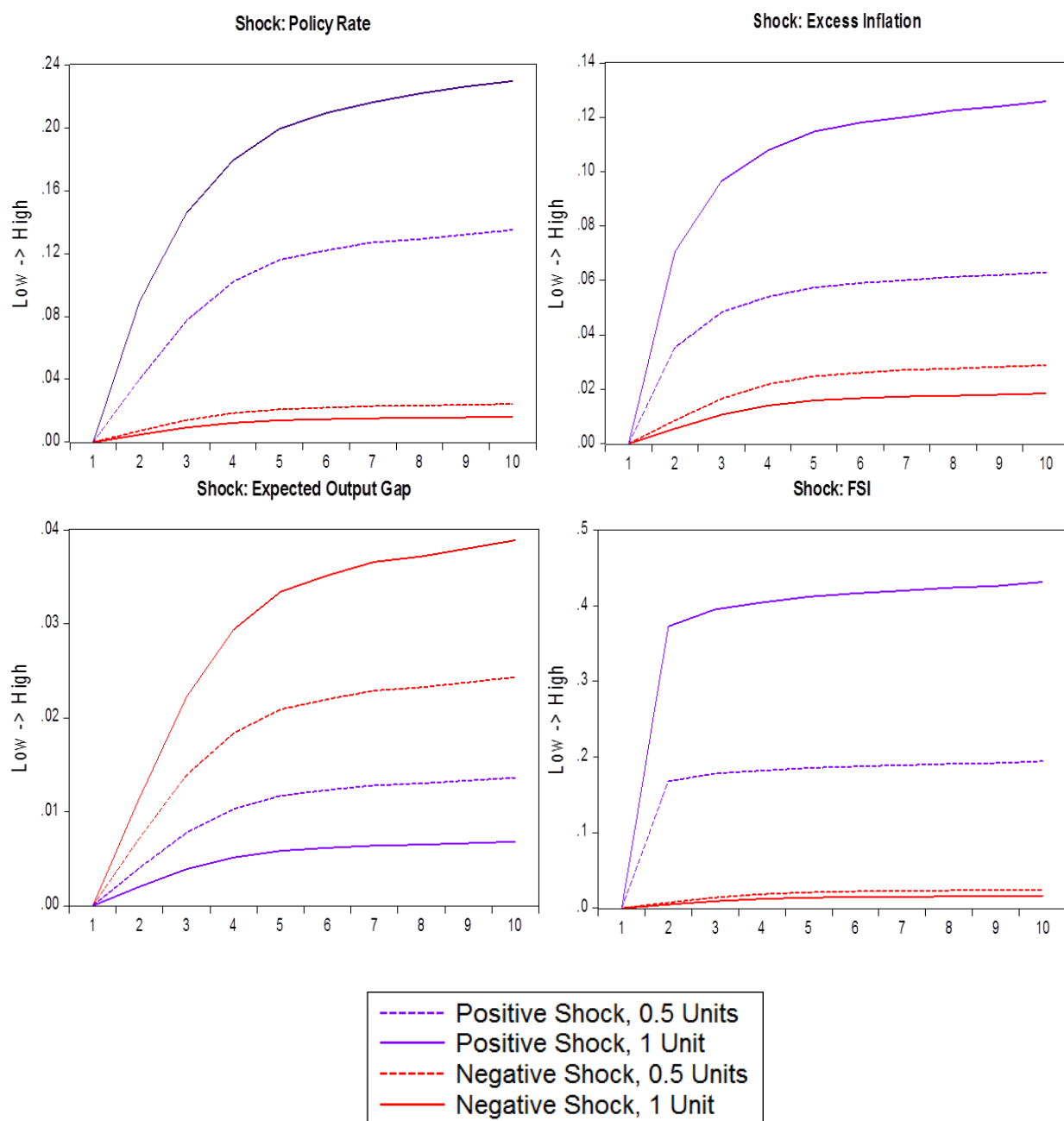
- A. *Corporate debt spreads* are defined as corporate bond yield minus long-term government bond yield. This captures the level of risk and uncertainty in the corporate debt market as well as incorporates credit, market and liquidity risk.
- B. *Stock market returns* are computed as the month-over-month change in the stock index multiplied by minus one, so that a decline in equity prices corresponds to increased securities-market-related stress.
- C. *Stock market volatility* is measured as the 6-month moving average of the squared month-on-month returns. This is used to capture when the financial markets are in a state of high uncertainty.

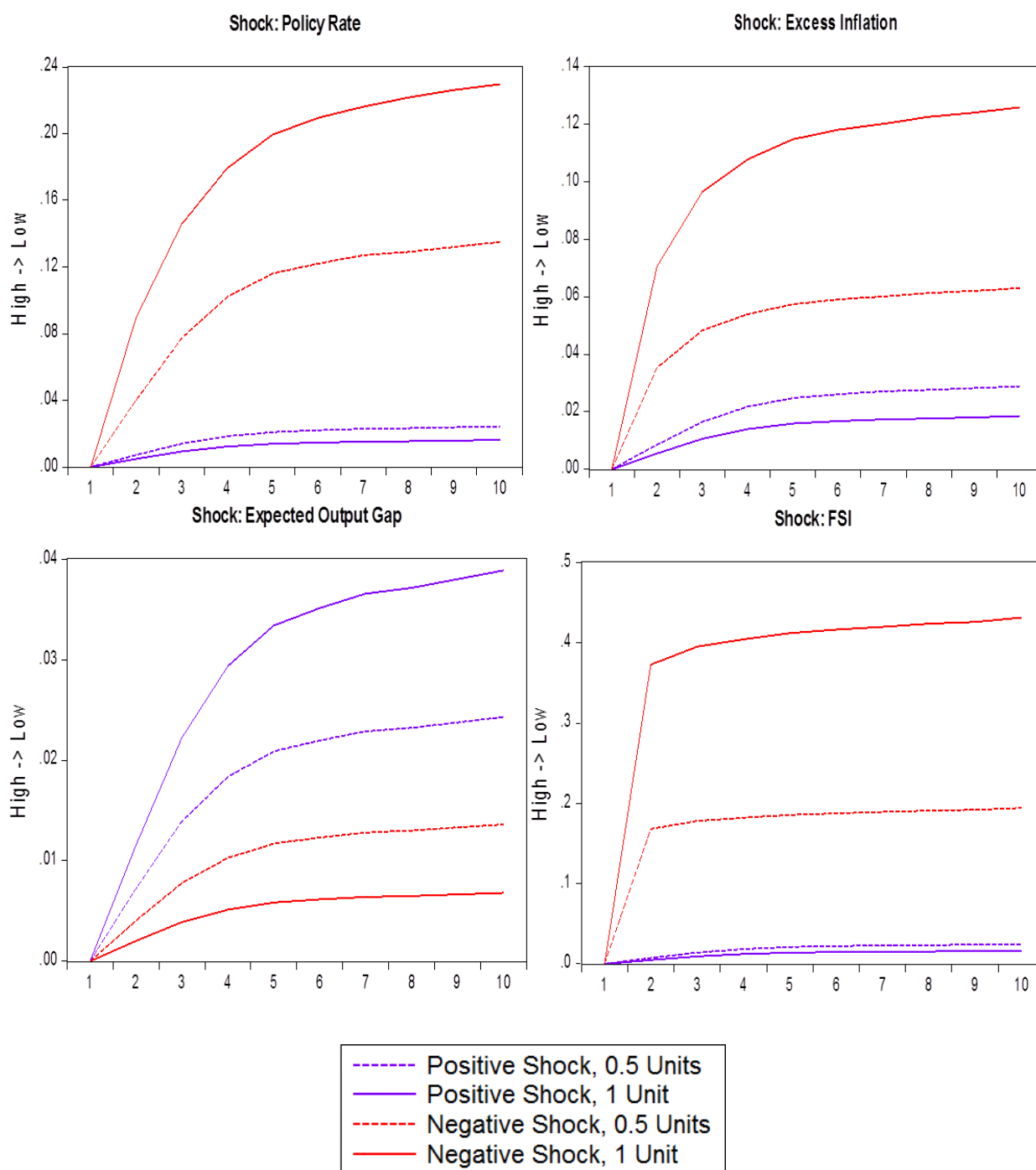
3. Foreign Exchange Market:

- A. The *foreign exchange market volatility* is measured as the 6-month moving average of the squared month-on-month growth rate of the exchange rate.

C: Regime Switching Probabilities

The empirical probabilities of regime switching between low and high financial stress is presented here.





The figures display the probability of a regime-switch following a shock at $t=1$. They are derived from the number of times that the switching variable (FSI) crossed its threshold and is plotted against the forecast horizon in which the switching occurs.